South Africa's 1st Annual Climate Change Report

Climate Change Trends, Risks, Impacts and Vulnerabilities

Theme C

environmental affairs

Department:
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The seven Themes of this Report are:

- **Theme A:** A Synopsis of South Africa's 2015 Annual Report on Monitoring Climate Change Responses
- **Theme B:** South Africa's Climate Change Monitoring and Evaluation System
- **Theme C:** Climate Change Trends, Risks, Impacts and Vulnerabilities
- **Theme D:** Tracking South Africa's Transition to a Lower Carbon Economy
- **Theme E:** Monitoring the Adaptation Landscape in South Africa: *Desired Adaptation Outcomes, Adaptation Projects and the Intended Nationally Determined Contribution*
- **Theme F:** Climate Finance
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FOREWORD BY MS. EDNA MOLEWA

MINISTER OF THE DEPARTMENT OF ENVIRONMENTAL AFFAIRS

Climate change is one of the greatest challenges of our time. As part of the global community, we know we shoulder an immense responsibility to deal with climate change and its impacts. The more we disrupt our climate, the more we risk severe, pervasive and irreversible impacts. That said - we do indeed have the means to limit climate change and build a more prosperous, sustainable future for our country and world, and all who live in it.

South Africa has endorsed the National Climate Change Response Policy as a vision and a framework for an effective climate change response, and the long-term, just transition to a climate-resilient economy and society. The policy is the product of an extensive consultation process. It sets two high-level objectives:

- ***Firstly***, to effectively manage the inevitable climate change impacts through interventions that build and sustain South Africa's social, economic and environmental resilience and emergency response capacity; and
- ***Secondly***, to make a fair contribution to the global effort to stabilise greenhouse gas (GHG) concentrations within a timeframe that enables economic, social and environmental development to proceed in a sustainable manner.

South Africa's approach towards an effective climate change response is both developmental and transformational. It is developmental in that we are prioritising climate change responses that have significant mitigation or adaptation benefits, AND have significant economic growth, job creation, public health, risk management and poverty alleviation benefits. It is transformational in that we are seeking to address climate change at a scale of economy that supports the required innovation and finance flows needed for a transition to a lower carbon, efficient, job creating, equitable and competitive economy. In essence, it is about sustainable development.

Work is well advanced in implementing this National Climate Change Response Policy. One of the key elements of the climate change response is a country-wide monitoring and evaluation system that tracks South Africa's transition to a lower carbon and climate resilient economy and society.

The main output of the climate change monitoring and evaluation system is South Africa's annual climate change report. This year, the Department will publish its first annual climate change report. This report focusses on (i) quantifying and profiling the impact of ongoing or recently completed mitigation actions (ii) updating the information on climate finance that was reported in South Africa's first Biennial Update Report (iii) providing latest available information on climate change risks together with describing ongoing adaptation projects (iv) presenting progress in establishing a credible tracking system for key climate change actions in the country (v) updating the roadmap on climate change flagship programmes (vi) recognising and profiling climate change actions that have been taken by the local government sphere of government and (vii) setting out key outcomes of the 21st Conference of Parties (COP 21) which took place in Paris in December 2015.

Internationally, South Africa submitted its own Intended Nationally Determined Contribution (INDC) to the United Nations Framework Convention on Climate Change (UNFCCC) Secretariat in September 2015. Our INDC encompasses three distinct components namely mitigation, adaptation and the means of implementation. The main aim of the next annual report (2016/17) is to initiate an in-depth annual process of reporting progress against South Africa's INDC.

Lastly, there is vast potential for co-operation in producing these annual reports. We recognise and thank all those that have assisted us to produce the first report. For this report, we received contributions from all three spheres of government, the private sector, civil society, foreign embassies, and academia. In addition, I would like to thank the German government for the extensive support that we have received through GIZ. We invite many others to continue the collaboration with us as we contribute towards the identification of opportunities for further climate change actions and management of current and future climate risks with the view to consolidating the gains that this country has attained so far by improving peoples' livelihoods, conserving biodiversity, and improving human well-being. We believe that by working together; we can save our tomorrow today.

Thank you

MS. EDNA MOLEWA

Minister of the Department of Environmental Affairs

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LIST OF ABBREVIATIONS

AAO	Antarctic Oscillation
ACCESS	Applied Centre for Climate and Earth System Studies
ACCESS1-0	Australian Community Climate and Earth System Simulator (Centre for Australian Weather and Climate Research)
ACDI	African Climate and Development Initiative
ACRU	Agricultural Catchments Research Unit
APSIM	Agricultural Production Systems Simulator
AR4	Fourth Assessment Report of the IPCC
AR5	Fifth Assessment Report of the IPCC
ARC	Agricultural Research Council
ARC-ISCW	ARC Institute for Soil, Climate and Water
BFAP	Bureau for Food and Agriculture Policy
CABLE	CSIRO Atmosphere Biosphere Land Exchange Model
CCAM	Conformal-Cubic Atmospheric Model
CCSM4	Community Climate System Model, Version 4 (University Corporation for Atmospheric Research, USA)
CGCM	coupled general circulation model
CHPC	Centre for High Performance Computing
CIP	Climate Information Portal (CSAG, UCT)
CMIP5	Coupled Model Intercomparison Project Phase 5
CMIPX	Coupled Model Intercomparison Project Phase X
CNRM-CM5	National Centre for Meteorological Research (France) Coupled Global Climate Model, Version 5
CO_2e	carbon dioxide equivalent
CORDEX	Co-ordinated Regional Downscaling Experiment
CRU TS3.1	Climatic Research Unit (University of East Anglia) Time Series 3.1
CRU	Climate Research Unit (Hadley Centre / University of East Anglia)
CSAG	Climate System Analysis Group (University of Cape Town)
CSIR	Council for Scientific and Industrial Research
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAFF	Department of Agriculture, Forestry and Fisheries
DEA	Department of Environmental Affairs
DJF	December, January, February (summer)
DSSAT	Decision Support System for Agrotechnology Transfer
DST	Department of Science and Technology
DWS	Department of Water and Sanitation
dtr	diurnal temperature range (the difference between daily Tmax and Tmin)
ECHAM5/MPI-OM	Coupled Climate Model Consisting of Atmospheric General Circulation Model (ECHAM5) and MPI-OM

	Ocean-Sea Ice Component, Max Planck Institute for Meteorology (MPIM), Hamburg, Germany
ENSO	El Niño-Southern Oscillation
GCGC	Global Change Grand Challenge
GCM	global climate model
GCRP	Global Change Research Plan
GDP	gross domestic product
GE	general equilibrium
GFDL-CMX	Geophysical Fluid Dynamics Laboratory Coupled Model, Version X (National Oceanic and Atmospheric Administration (NOAA), Geophysical Fluid Dynamics Laboratory USA)
IOD	Indian Ocean Dipole
IPCC	Intergovernmental Panel on Climate Change
JJA	June, July, August (winter)
KZN	KwaZulu-Natal
LTAS	Long-Term Adaptation Scenarios Flagship Research Programme
M&E	monitoring and evaluation
MAM	March, April, May (autumn)
MAP	mean annual precipitation
MDG	Millennium Development Goals
MIROC3.2-medres	Model for Interdisciplinary Research on Climate, medium resolution (Centre for Climate System Research (CCSR) of the University of Tokyo, National Institute for Environmental Studies (NIES), Frontier Research Centre for Global Change (FRCGC), Japan Agency for Marine-Earth Science and Technology (JAMSTEC)
MIROC4h	Model for Interdisciplinary Research on Climate (Atmosphere and Ocean Research Institute (AORI) of the University of Tokyo, the National Institute for Environmental Studies (NIES) and the Japan Agency for Marine-Earth Science and Technology (JAMSTEC))
MIT	Massachusetts Institute of Technology
MJO	Madden-Julian Oscillation
MPI-ESM-LR	coupled Max Planck Institute Earth System Model at base resolution
MRI-GCM3	Meteorological Research Institute Global Climate Model, Version 3 (Japan Meteorological Agency (JMA))
NCCRWP	National Climate Change Response White Paper
NDMC	National Disaster Management Centre
NorESM1-M	Norwegian Earth System Model, Part 1 (Norwegian Climate Centre)
NRF	National Research Foundation
PDF	probability density function
ppm	parts per million
ppt	precipitation
RCP	Representative Concentration Pathway
RIV	risks, impacts and vulnerabilities
SAEON	South African Environmental Observation Network
SACRED	Systematic Assessment of Climate Resilient Development
SANBI	South African National Biodiversity Institute

SANReN	South African National Research Network
SARVA	South African Risk and Vulnerability Atlas
SASSCAL	Southern African Science Service Centre for Climate Change and Adaptive Land Use
SAWS	South African Weather Service
SOI	Southern Oscillation Index
SON	September, October, November (spring)
SRES	Special Report on Emissions Scenarios
SST	sea surface temperature
StatsSA	Statistics South Africa
tmax	maximum temperature
tmin	minimum temperature
UCT	University of Cape Town
UKMO-HadCM3	United Kingdom Met Office, Hadley Centre Coupled Model, Version 3
UNFCCC	United Nations Framework Convention on Climate Change
WG1	Working Group One, IPCC
WG2	Working Group Two, IPCC
WMA	water management area
WMO	World Meteorological Organisation
WRC	Water Research Commission
WWF-SA	World Wide Fund for Nature South Africa

1. OBSERVED TRENDS IN THE CLIMATE OF SOUTH AFRICA

1.1 Overview

This Theme is based on the most up-to-date scientific literature up to the end of 2015 describing observed trends in the climate of South Africa. The Africa Chapter of Assessment Report Five (AR5) of the Intergovernmental Panel on Climate Change (IPCC) Working Group Two (WG2) (Niang et al. 2014), together with the Working Group One (WG1) report of AR5 (IPCC 2013) provide the global context to this Theme. These IPCC reports describe observed trends in African climate, and make use of general circulation models (GCMs) to describe the large scale climatic changes that are projected in Africa for a range of mitigation futures. Nationally generated information is also extensively referenced and summarised, including the most recent synthesis by the South African Weather Service (SAWS 2015).

Within South Africa, research is ongoing to detect climatic changes which are already observable in the country, and to develop locally relevant projections of future climate change. This is reported in the international and national literature and via formal annual reporting channels to the World Meteorological Organisation (WMO) by SAWS. The analysis of observed trends is based largely on stations selected from the thousands of weather stations managed by SAWS and the Agricultural Research Council (ARC), most of which measure daily rainfall and temperature as a minimum observation set.

Locally relevant projections of regional climate change over South Africa have also been generated in recent years at the Council for Scientific and Industrial Research (CSIR) and the University of Cape Town (UCT). These programmes collaborate internationally, including in the Co-ordinated Regional Downscaling Experiment (CORDEX) of the World Climate Research Programme, which has begun to disseminate high-resolution projections of future climate change over Africa. Several scientifically reviewed outputs describing projected changes over South Africa have been produced to date.

The results described in this Theme have been sourced from reviewed outputs in science journals and stakeholder reviewed reports, with reports by SAWS and South Africa's Long-Term Adaptation Scenarios Flagship Research Programme, (LTAS), 2012–2014 of the Department of Environmental Affairs (DEA) being of particular importance. The latter, a multi-sectoral research programme, was mandated by the South African National Climate Change Response White Paper (NCCRWP DEA 2011a, para. 8.8). The LTAS aimed at providing an updated national perspective on climate change trends and projections that advanced upon that presented in the Second National Communication under the UNFCCC (DEA 2011b), and from this proceeded to develop national and sub-national adaptation scenarios for South Africa under plausible future climate conditions and development pathways. The LTAS reports included a technical report on observed climate trends and projected climate change futures for South Africa (DEA 2013).

The climate trends described in this review Theme are presented in the form of maps and statistics at national scale, with the discussion also summarising trends at provincial scale (the scale at which locally relevant decisions are made). Emphasis is placed not only on the observed changes in average rainfall and temperature, but also on their extremes (for example heat waves, droughts and heavy rainfall events). The primary purpose of this document is to report both on observed trends in climate and the most recently generated projections of future climate change over South Africa, which are briefly summarised.

The Theme also identifies important national initiatives in South Africa aimed at and co-ordinating research on detecting trends in climate and projecting climate change futures. At the national scale these include the LTAS under the DEA, the Global Change Grand Challenge (GCGC) of the Department of Science and Technology (DST), particularly through the Applied Centre for Climate and

Earth System Studies (ACCESS) and the South African Risk and Vulnerability Atlas (SARVA). At the southern African level, the activities of the recently established Southern African Science Service Centre for Climate Change and Adaptive Land Use (SASSCAL) are highlighted.

1.2 Observed Climate Trends in South Africa

A number of systematic changes in the temperature and rainfall climatologies of South Africa have occurred over the past five decades, as detected in the weather station data of SAWS and ARC, and the related gridded data sets of the Climatic Research Unit (CRU) in the United Kingdom. These trends have been documented in peer-reviewed research papers published by researchers from SAWS, UCT and the CSIR over the past few years, with many of these results summarised and documented in the LTAS reports of the DEA and AR5 of the IPCC. The period of analysis of these studies generally spans the five decades 1960–2010.

Analyses of observed trends in climate are available not only for South Africa at national level, but also at provincial scale and for individual weather stations (Kruger 2006; Kruger & Sekele 2013; Kruger & Shongwe 2004; MacKellar et al. 2014). Analyses have also been performed more broadly for southern Africa and the sub-Saharan African region (Engelbrecht et al. 2014;

Veld before the storm

Hulme et al. 2001; New et al. 2006). Only a few efforts have been made to compare historically observed trends with trends simulated for the same period by various modelling approaches (Engelbrecht et al. 2015; MacKellar et al. 2014). This is important for verifying climate models and also to gain insights into the circulation changes responsible for the observed changes in temperature and rainfall. In addition to trend analysis, new work has emerged that analyses not only the long term trends, but also the drivers of climate variability at various time scales, from the decadal to the diurnal (Malherbe et al. 2013a; Malherbe et al. 2016; Reason 2001; Reason et al. 2000; Reason & Rouault 2002). An understanding of these drivers and the resulting patterns of variability is important, as they determine current climate risks and impacts, how present-day variability can be predicted with the current tools available, and how present-day variability may be affected by long term climate change.

South Africa has one of the densest climate monitoring systems in Africa and much of the Southern Hemisphere (Easterling et al. 2000; Hughes & Balling 1995; New et al. 2006), but the number and location of weather stations has not remained constant over time, and measuring technology has changed and continues to do so. This makes it possible to investigate trends and variability over multiple decades, but the results of climate trend analyses can be strongly affected by the choice of start and end dates, and the quality and density of climatic data that are considered. It is therefore critical that such investigations clearly describe the data employed with respect to source, quality control and data cleaning methodology and interpolation procedures, if relevant.

A comprehensive agro-hydrological climatology that was developed for South Africa by the Centre for Water Resources Research at the University of KwaZulu-Natal (Schulze 2008) carried out vital quality control work on South African daily climate data from 1950 to 1999 for weather stations obtained from SAWS, ARC and other credible sources. This product provides a large number of key climatic and hydrological variables derived from the daily data for the period 1950–99, with associated trends analysis, but has not been updated with new data since 2000. As a result, most climate trend analyses conducted recently in South Africa have focused on relatively few weather stations of SAWS and in some cases also stations from the Computing Centre for Water Resources of the Department of Water and Sanitation (DWS). Each of these studies required data quality control procedures to be applied first, in the absence of a national database that should be providing a quality controlled dataset derived from SAWS, ARC and DWS stations.

Recently the ARC Institute for Soil, Climate and Water (ARC-ISCW) prepared a scientific report for the Department of Agriculture, Forestry and Fisheries (DAFF) on "The sensitivity of crop suitability to climate change in South Africa" (Weepener et. al. 2014). Two aspects were addressed: firstly, the potential shift of climatic regions over South Africa under climate change using the Köppen-Geiger climate zone classification, and secondly, the potential shifts in crop production areas for twelve crops. The most striking projected change in climatic zones over South Africa is the expansion of the hot desert zone. The expansion of this zone to the east over the central interior of the country is at the expense of western extremities of agricultural land characterised by marginal to sub-optimal suitability for production of maize, soybean, sorghum and sunflower. The researchers succeeded in providing evidence that rising levels of CO_2 will impact increasingly on vegetation change over coming decades and that different crops are not affected to the same degree by climate change. Rising temperature is the main cause of shifts in production areas. These areas could decrease for most crops (examples include maize, soybean, sorghum, sunflower, potato and Smuts finger grass), increase for other crops (sugarcane, groundnut and cotton) or remain largely unchanged (wheat). Current production areas for macadamia and avocado could become marginal or unsuitable in future, while large areas in KwaZulu-Natal could become suitable. Producers will need to adapt to these changing conditions in order to remain in a position to provide for the demand in agricultural commodities.

1.2.1 Temperature trends

1.2.1.1 Observed temperature trends

South Africa's national temperature monitoring network consists of several hundred stations belonging to SAWS, ARC and other institutions. Previous national analyses of temperature patterns (Schulze 2008) used techniques based on regionalised temperature lapse rates to combine and quality control the SAWS and other data to interpolate these data sets to a fine spatial scale (1 x 1 arcminute, namely approximately 1.7 x 1.7 km). However, this effort of generating a national database ceased in 2004. More recent temperature trends analyses for South Africa generally have relied only on SAWS data. Of the SAWS stations, only between 30 and 40 have a record with less than 20% of missing data (**Figure 1.1**). A similar number of stations have more than 80% missing data. As a result, trend analysis can typically be performed for tens, rather than for hundreds of stations.

A number of recent studies describing temperature trends over Africa and South Africa are relevant to this report. The first is the Africa chapter of AR5 of the IPCC, which summarises temperature trends over Africa at a large spatial scale and presents an assessment of the data quality and model efficacy in replicating trends (Niang et al. 2014). A more recent analysis of regional temperature change and comparison with modelled trends is presented by Engelbrecht et al. (2015), who have conducted an analysis for the whole of Africa at a greater level of spatial detail, and with access to apparently more data than that summarised by the IPCC. At national level a relevant analysis is that of MacKellar et al. (2014), derived from LTAS (DEA 2013), which provides a national view and a comparison with a set of modelled trends, as well as the station-level analysis of Kruger and Shongwe (2004).

The analysis of MacKellar et al. (2014) demonstrates that maximum and minimum temperatures all show significant increases virtually at every station, both when

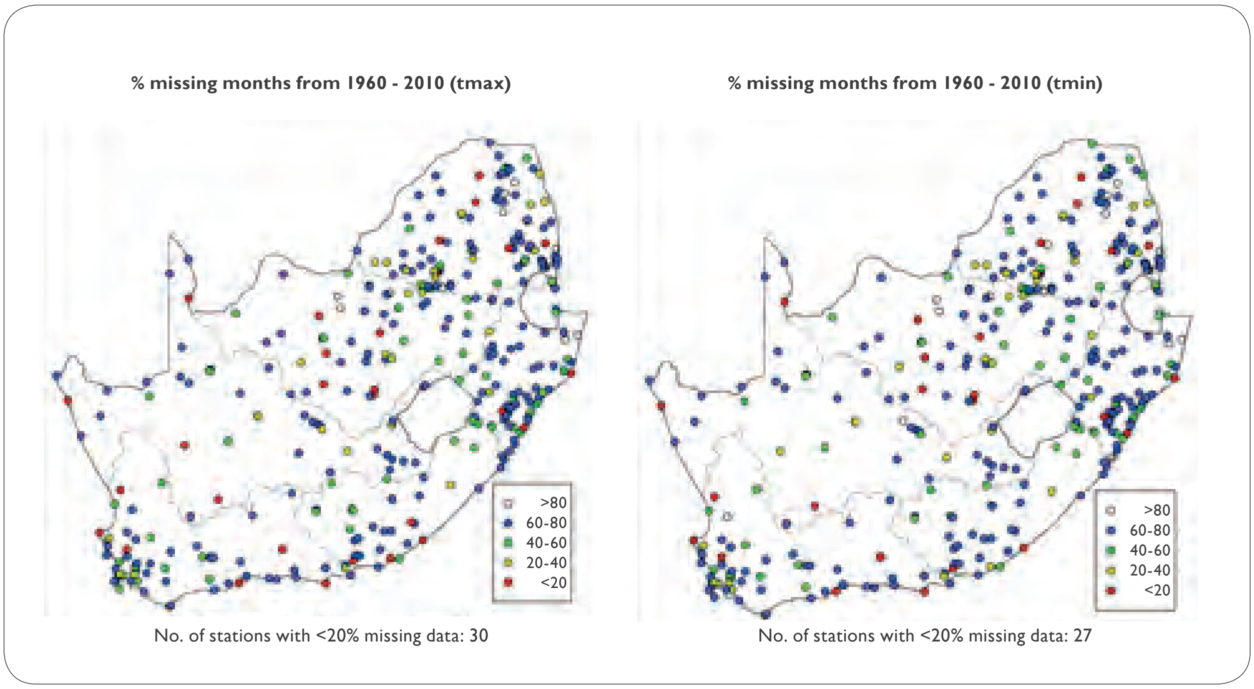


Figure 1.1: Station coverage (left) for maximum temperature and (right) for minimum temperature (adapted from DEA 2013)

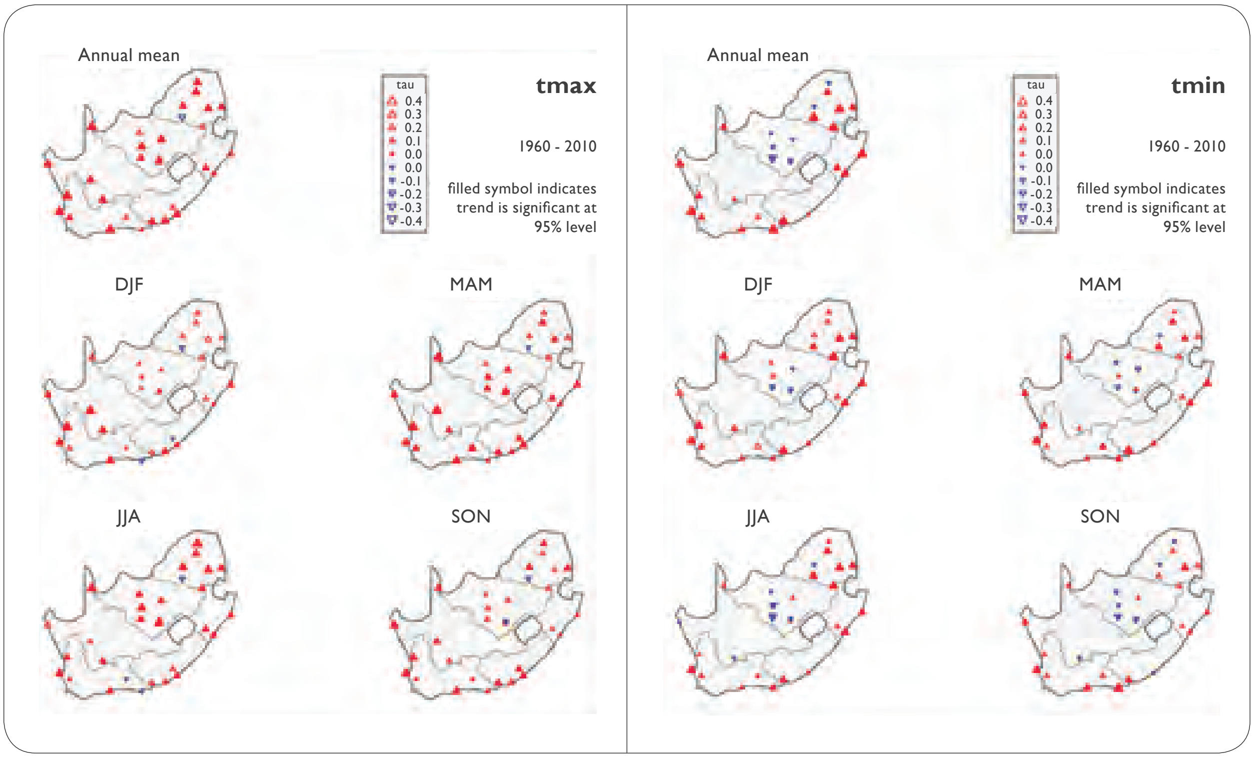


Figure 1.2: Trends in annual and seasonal maximum temperatures (left) and minimum temperatures (right) for each station according to the Mann-Kendall test (the value of Kendall's tau, a correlation coefficient, represents the direction and relative strength of the trend. Filled symbols indicate trends that are significant at the 95% level for the summer [DJF], autumn [MAM], winter [JJA] and spring [SON] seasons) (adapted from DEA 2013)

analysed annually and when analysed for the four seasons of winter (June to August [JJA]), spring (September to November [SON]), summer (December to February [DJF]) and autumn (March to May [MAM]). Maximum temperatures have increased more significantly than minimum temperatures, and the strongest seasonal increases in both maximum and minimum temperatures have occurred in the autumn and winter months. The only exception to the pattern of national increases in temperature is the central interior, where no change, or even decreases, can be noted for minimum temperature (**Figure 1.2**). These decreases in minimum temperature have been detected for all seasons and annually, although the trends are strongest for winter.

As may be expected from the above, high temperature extremes have increased significantly in frequency, and low temperature extremes have decreased significantly in frequency (**Figure 1.3**). Consistent with the trends in annual average temperature, extreme low temperature events have increased to some extent in the central interior. The net result with respect to daily temperature range (**Figure 1.4**) presents a more complex picture, with strongest increases noted in the interior, and weaker increases at coastal observation points. This could indicate a buffering effect of the oceanic influence on temperature change, with the interior experiencing the strongest increases in maximum temperatures but also decreases in minimum temperatures. These results from LTAS DEA (2013) and MacKellar et al. (2014) update and confirm earlier national level analyses by Kruger and Shongwe (2004) and by Kruger and Selele (2013), who also demonstrated substantial increases in mean, minimum and maximum temperatures annually and on a seasonal basis.

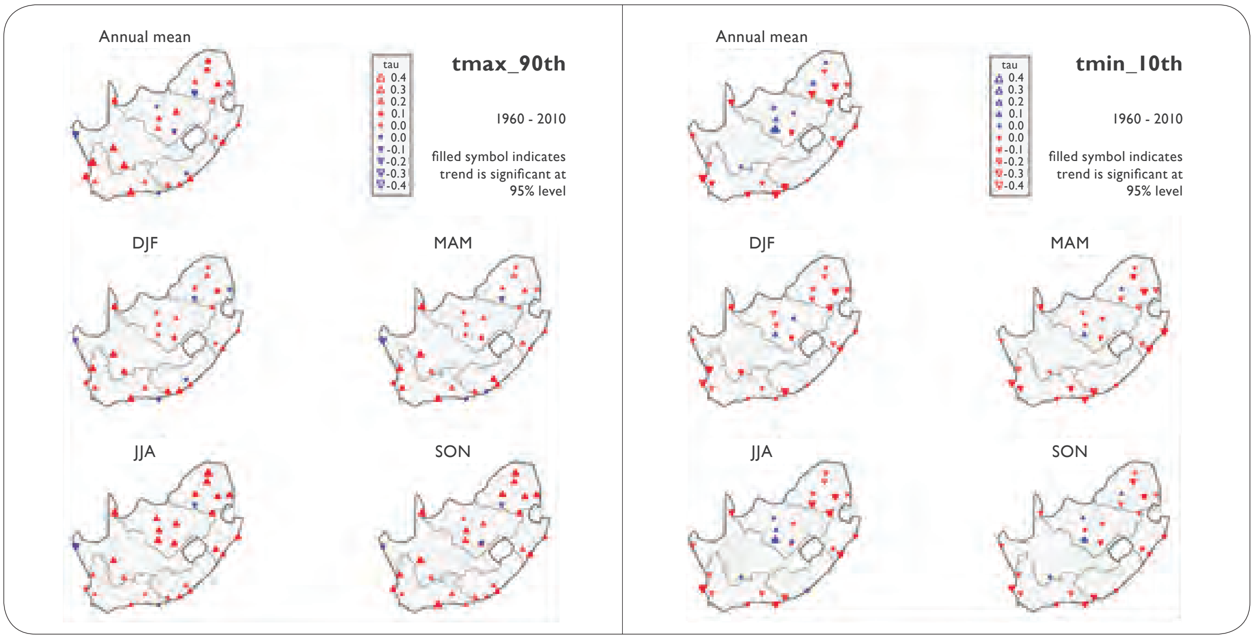


Figure 1.3: Trends in annual and seasonal number of days above the 90th percentile maximum temperature (left) and the 10th percentile minimum temperature (right) for each station according to the Mann-Kendall test (The value of Kendall's tau, a correlation coefficient, represents the direction and relative strength of the trend. Filled symbols indicate trends that are significant at the 95% level for the summer [DJF], autumn [MAM], winter [JJA] and spring [SON] seasons) (adapted from DEA 2013)

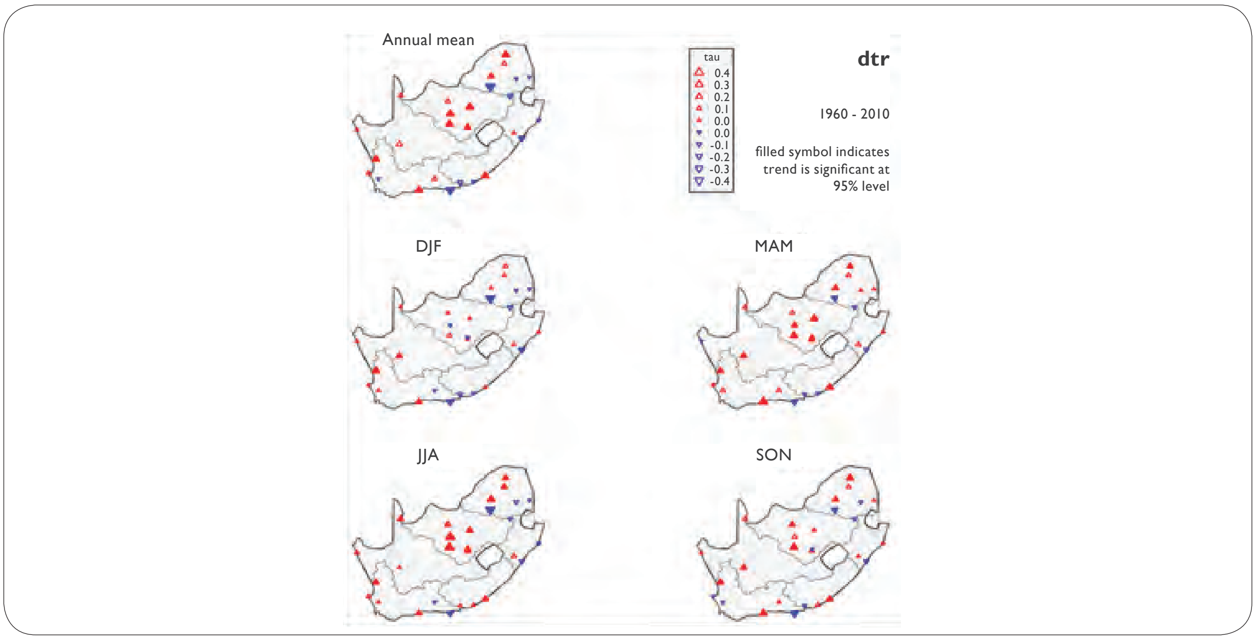


Figure 1.4: Trends in annual and seasonal daily temperature range for each station according to the Mann-Kendall test (The value of Kendell's tau, a correlation coefficient, represents the direction and relative strength of the trend. Filled symbols indicate trends that are significant at the 95% level for the summer [DJF], autumn [MAM], winter [JJA] and spring [SON] seasons) (adapted from DEA 2013)

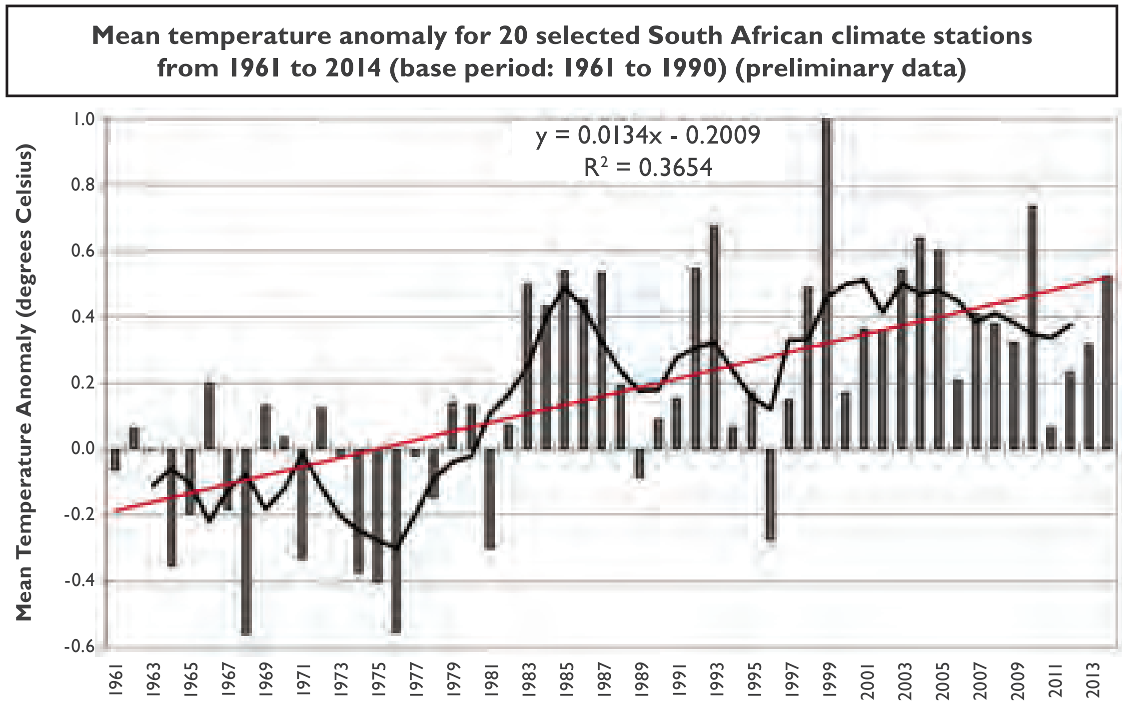


Figure 1.5: Annual mean temperature anomalies (base period 1961–1990) of 20 climate stations in South Africa for the period 1961–2014, with the red line indicating the linear trend and the black line the 5-year moving average (SAWS 2015)

The most relevant recent analysis of long term national temperature trends is that presented annually by SAWS to the WMO (**Figure 1.5**). This analysis shows annual temperature trends to have increased significantly between 1960 and 2014, but that the increase shows fluctuations (variability) in rate. The highest rates of increase were recorded from the mid-1970s to the early 1980s, followed by a period of fluctuation, and with a further warming trend observable again in the late 1990s to the mid-2000s. This warming was again followed by a period of temperature fluctuation. Since 2011, temperature trends have again been upward, following a stabilisation in the warming trend. The SAWS reports reveal that for the 20 selected stations used nationally, the annual temperatures have trended upwards each year from 2011, but have not achieved the high temperatures recorded in 1999, 2010 and 1993, respectively, and some years in the early 2000s and 1980s. SAWS has also reported that warming trends accelerated from the 1960s (SAWS 2015).

The analyses of Engelbrecht et al. (2015) and Niang et al. (2014) place these national trends in a regional and a continental context. Engelbrecht et al. (2015) presents an analysis based on the land station temperature data set, CRUTEM4v of the CRU. This comprises homogenised time series data for 5° longitude × 5° latitude grids. The analysis is compromised to some degree by large data gaps, because trends were only calculated for grids with a minimum of 30 years of data available over the 50 year period from 1961 to 2010. Results show that temperature increases over the past five decades have been significant over most of the African continent, but particularly in

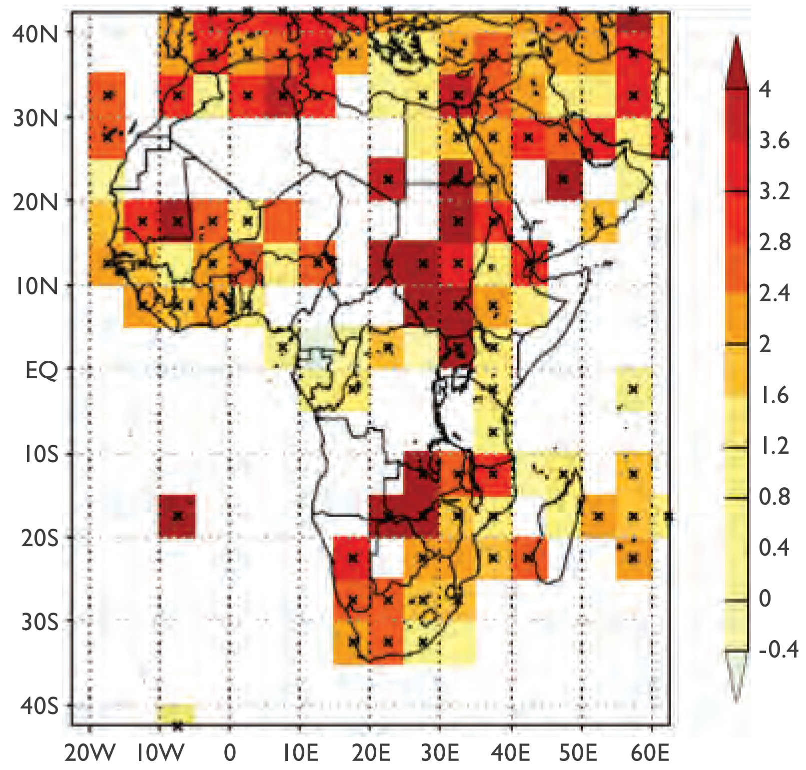


Figure 1.6: Observed trends in annual average near surface temperatures (degrees / century) between 1961 and 2010 for the African continent with statistical significance indicated by "x" (Source: Engelbrecht et al., 2015)

southern Africa in the subtropics (**Figure 1.6**). The strongest trends (more than 3 °C / century) are noted in subtropical southern Africa, but large increases are also seen in central tropical Africa and subtropical North Africa. Importantly, the observed rate of temperature increase over southern Africa is more than double the global rate of warming on land.

Niang et al. (2014), in the Africa chapter of AR5, provide a useful analysis of increasing warming trends globally from the early 1900s (**Figure 1.7**). From this it can be seen that the African continent and central Asia show among the most rapid warming trends since the 1980s, concurring with the results of Engelbrecht et al. (2015), except in terms of spatial detail, with the major warming in southern Africa not apparent in the results of Niang et al. (2014).

1.2.1.2 Modelled temperature trends and comparison with observed trends

Only two of the recently published pieces on observed trends have also presented modelled trends for the time period concerned, namely those by MacKellar et al. (2014) and Engelbrecht et al. (2015). Engelbrecht et al. (2015) presented the results from six GCMs, all downscaled to the African continent using the CCAM (Conformal-Cubic Atmospheric Model) regional model (**Figure 1.8**).

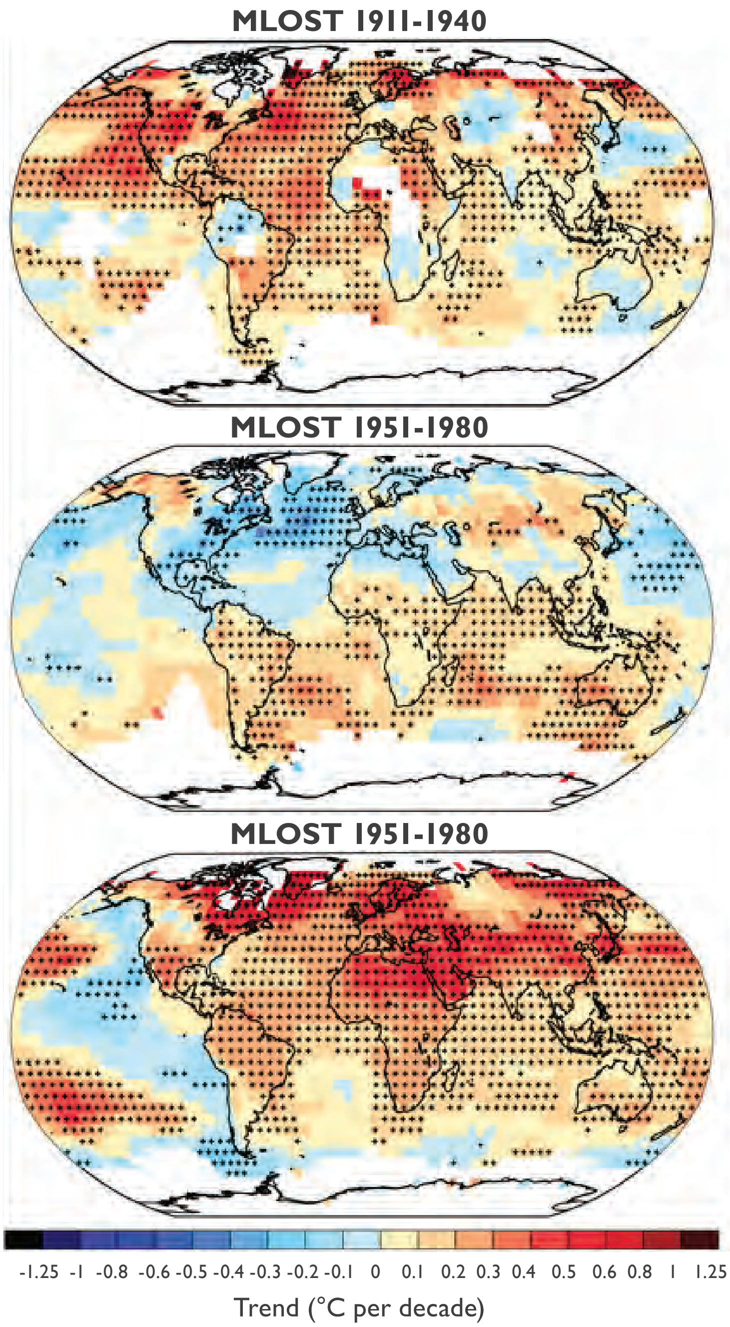


Figure 1.7: Observed trends in annual average near surface temperatures (°C / decade) between 1911 and 2012 for the planet, with statistical significance indicated by "+" (Niang et al. 2014)

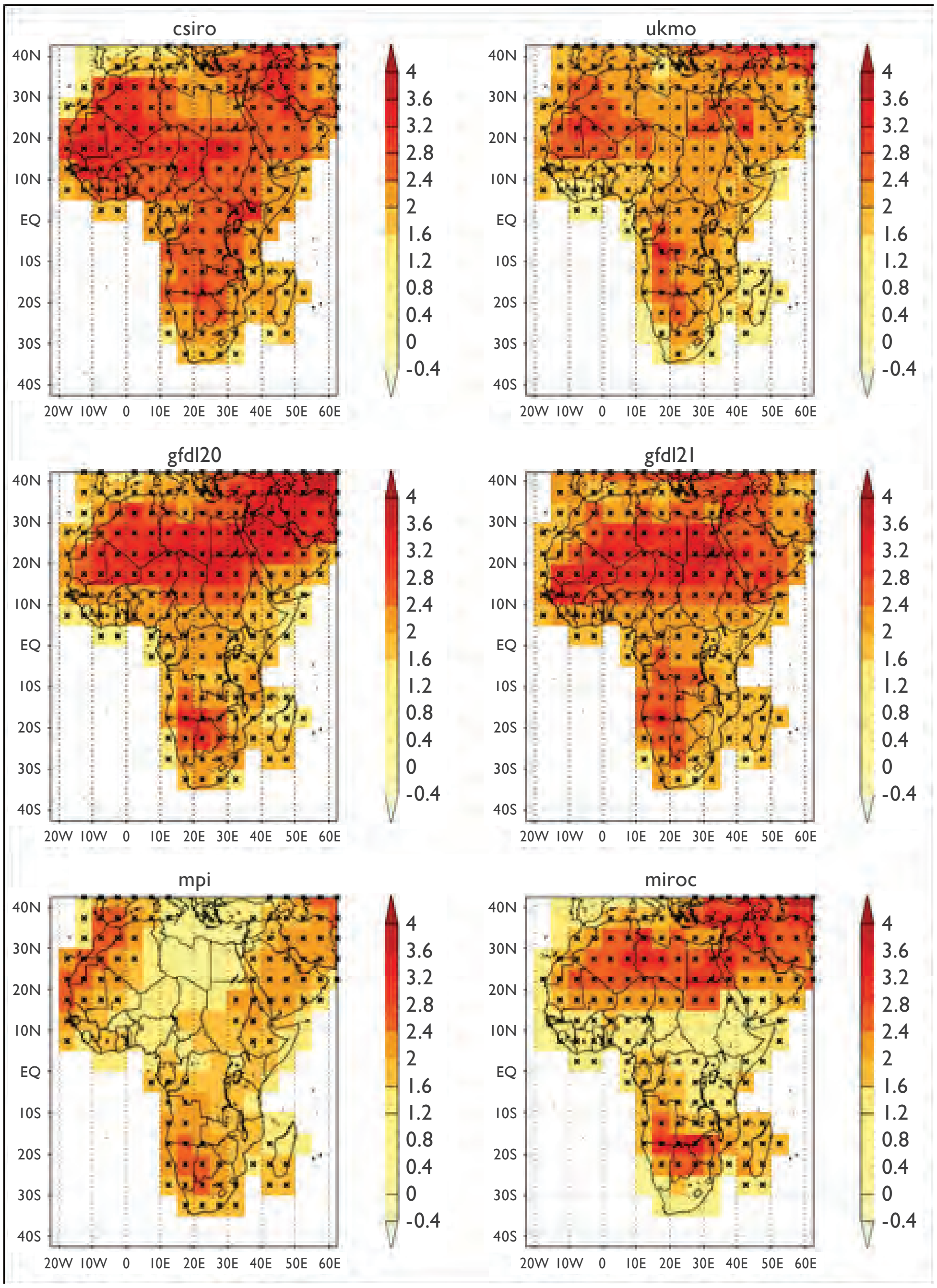


Figure 1.8: Modelled trends in annual average near surface temperatures (°C / century) between 1961 and 2010 for the African continent, as simulated by six GCMs, with statistical significance indicated by "x" (Engelbrecht et al. 2015)

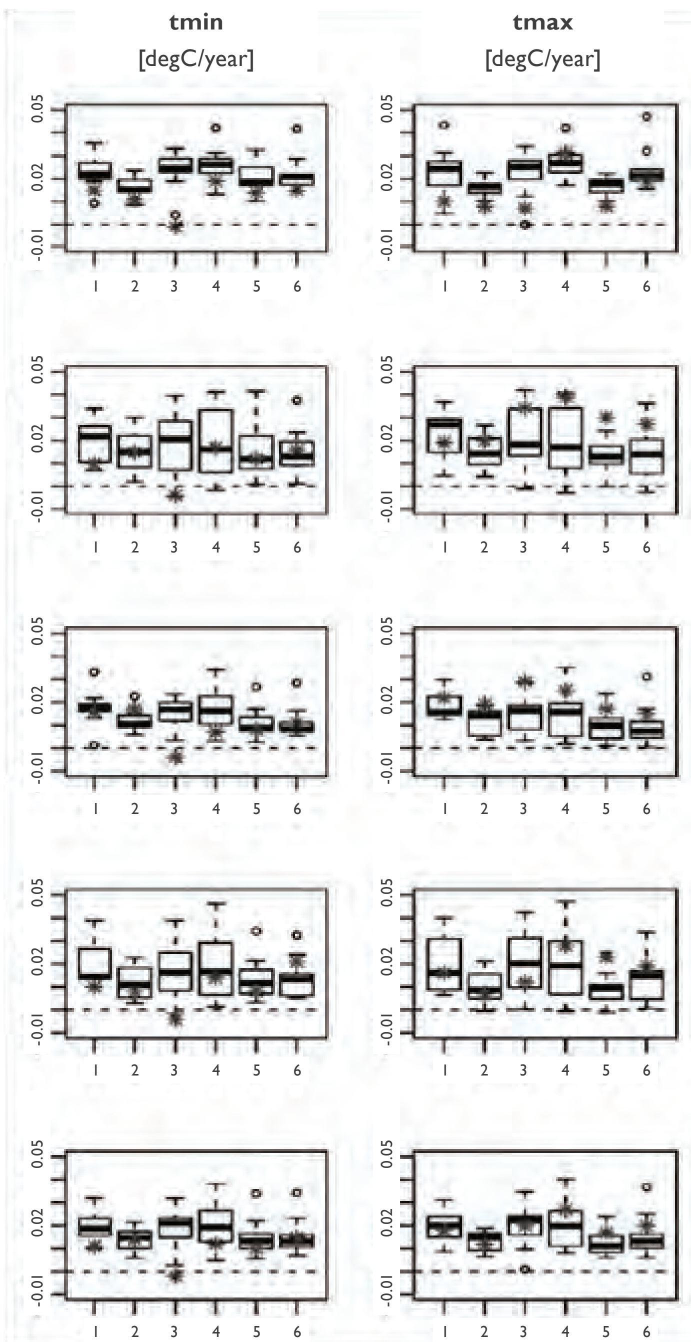


Figure 1.9: Comparison between observed trends and statistically downscaled GCM trends of maximum (right column) and minimum temperatures (left column) for 1960–2010, with trends averaged for stations in each of six water management regions into which South Africa was delineated for summer (DJF, top two maps), autumn (MAM, next two), winter (JJA), spring (SON) and annual (Ann, bottom maps) means. Asterisks show observed trend and box-and-whisker plots represent the 11 downscaled model trends, with circles indicating models lying outside 1.5 times the inter-quartile range (from MacKellar et al., 2014).

The results reveal that, similar to the observed trends, a significant warming trend occurs in all six model simulations. However, there is variance between the six models, indicating significant differences in their sensitivity to change. While all simulate greater levels of warming in subtropical versus tropical latitudes, and lower levels of coastal than interior warming, there remain differences between the models in finer details of the simulated spatial pattern of warming. This pattern of warming matches to some degree the observed warming, but the lack of available data for many regions of tropical and subtropical Africa prevents a clear conclusion about the degree of matching between models and observations.

A detailed analysis comparing observed and modelled trends has also been conducted by MacKellar et al. (2014) at the national scale for the time period 1960–2010 (**Figure 1.9**). These authors found that, overall, patterns and amounts of warming were fairly well reproduced by the models at the annual time scale, but that these patterns were regionally specific with respect to accuracy at the seasonal time scale.

1.2.2 Observed rainfall trends

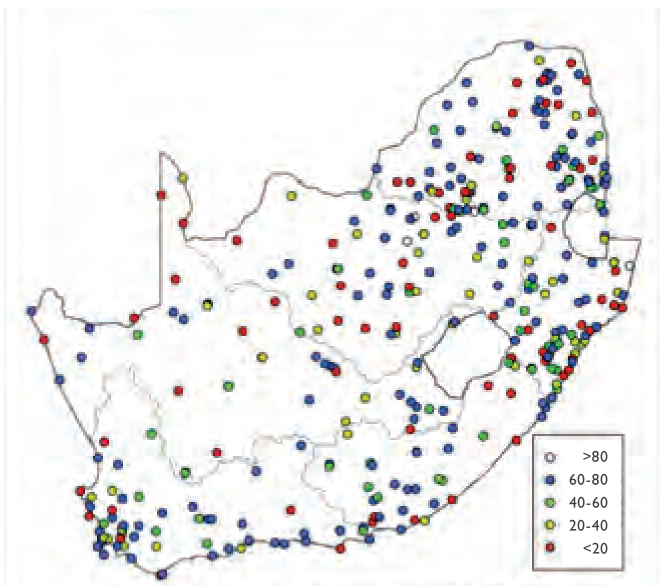
South Africa's mean annual precipitation (MAP) is highly variable from year to year (Tyson 1986; Mason & Jury 1997; Schulze 2008) and, as a result, few spatially coherent or statistically significant trends can be observed (Kruger 2006; MacKellar et al. 2014; Nel 2009; New et al. 2006). Also of importance is the seasonal distribution of rainfall, including the onset and end of the rainy season, the typical duration of wet and dry periods and the frequency of occurrence of heavy rainfall events. A review by Easterling et al. (2000) indicates a tendency for increased extreme precipitation in the southwestern and eastern parts of South Africa during most of the 20th century. This is supported by Groisman et al. (2005), who showed a significant increase in the annual frequency of very heavy rainfall events over eastern South Africa from 1906–97. Mason et al. (1999) also demonstrated increases in the intensity of high rainfall events in the 1961–90 period, relative to 1931–60, over much of South Africa. Kruger (2006) showed increases in extreme rainfall indices over the southern Free State and parts of the Eastern Cape

Thunderstorm

from 1910–2004. New et al. (2006) also showed some evidence for increased rainfall extremes over parts of South Africa for the 1961–2000 period. Nel (2009) demonstrated a shift in seasonality for stations in the KwaZulu-Natal (KZN) Drakensberg for 1955–2000. In the latter study, MAP showed no significant trend, but an increase in summer rainfall was accompanied by decreased autumn and winter rainfall, resulting in a shorter wet season and a more pronounced seasonal cycle. This is consistent with results from Thomas et al. (2007) for north-western KZN, where an increase in early season rainfall has been observed along with a decrease in late season rainfall between 1950 and 2000. Seasonal shifts were also observed by Thomas et al. (2007) in Limpopo for the same period, where there has been a tendency for a later seasonal rainfall onset accompanied by increased dry spells and fewer rain days. Increased dry spell duration is also evident for much of the Free State and Eastern Cape, and decreases in wet spell duration have been observed for parts of the Eastern Cape and the north-eastern parts of South Africa during the 1910–2004 period (Kruger 2006).

Trends in rainfall attributes over South Africa analysed recently by DEA (2013) and MacKellar et al. (2014) are displayed in **Figures 1.11** and **1.12**. The results are based on 72 SAWS weather stations for which fewer than 20% of data are missing for the 1960–2000 period (**Figure 1.10**). Overall, trends in rainfall totals are weak and non-significant (**Figure 1.11**, left maps), but there is a tendency towards a significant decrease in the number of rain days (**Figure 1.11**, right maps). There is some evidence of increasing trends in rainfall totals over the central interior of South Africa (**Figure 1.11**, left maps). There is a tendency towards an increase in rainfall extreme events, especially in spring and summer over the central interior, with a reduction in extremes in autumn (**Figure 1.12**). These results are consistent with those obtained independently by Kruger (2006), and earlier detailed analyses by Warburton et al. (2005a, b)

% missing months from 1960-2010 (ppt)



No. of stations with <20% missing data: 73

Figure 1.10: Station coverage for precipitation trend studies by DEA (2013) and MacKellar et al. (2014)

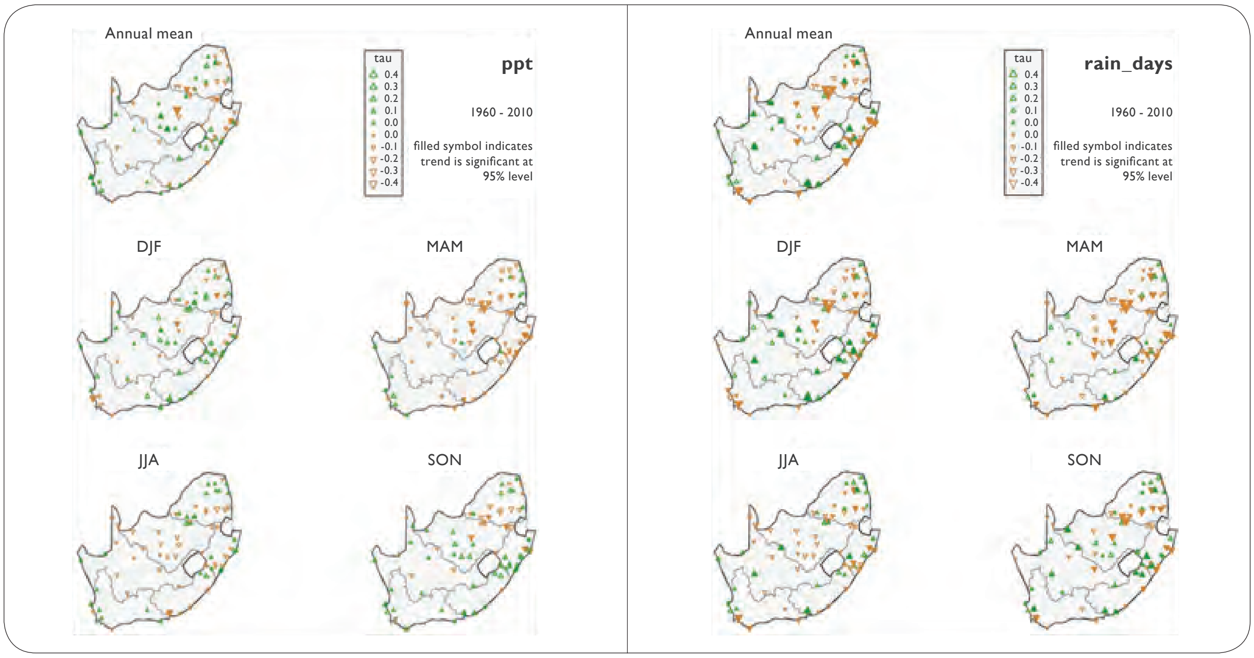


Figure 1.11: Trends in annual and seasonal mean rainfall (left maps) and numbers of rain days (right maps) for each of 72 stations according to the Mann-Kendall test, with the value of tau representing the direction and relative strength of the trend, and shaded symbols denoting trends that are significant at the 95% level for the summer (DJF), autumn (MAM), winter (JJA) and spring (SON) seasons (from DEA 2013)

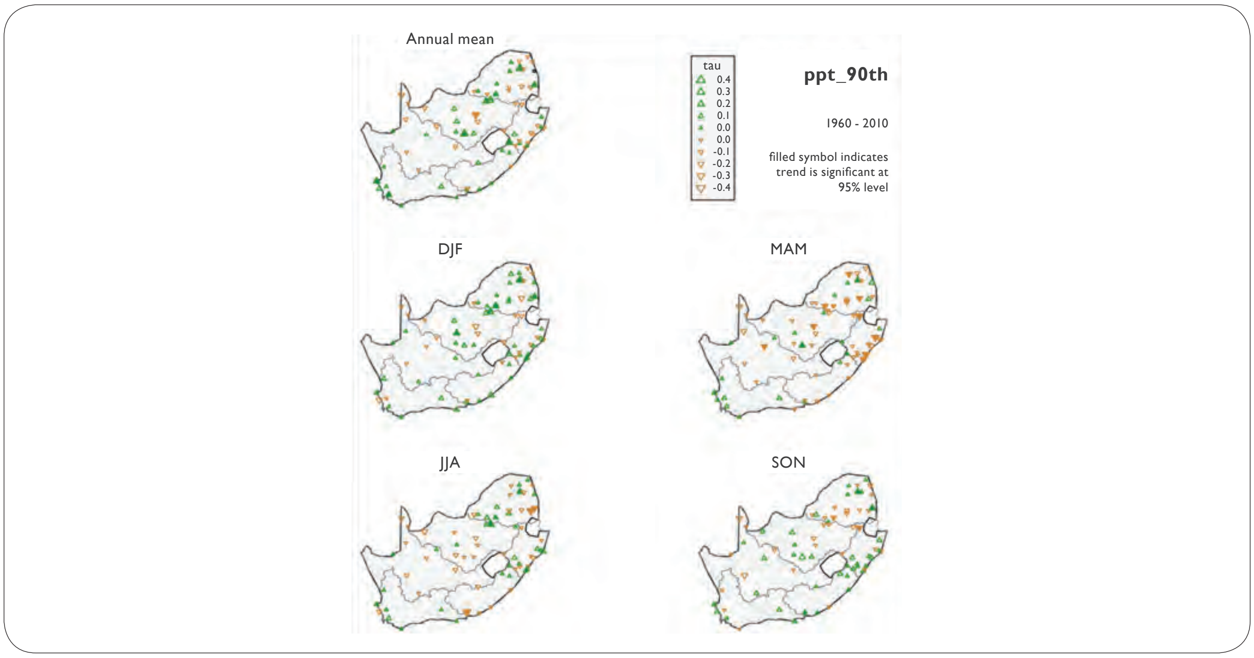


Figure 1.12: Trends in annual and seasonal number of days above the 90th percentile rainfall for each of 72 stations according to the Mann-Kendall test, with the value of tau representing the direction and relative strength of the trend, and shaded symbols denoting trends that are significant at the 95% level for the summer (DJF), autumn (MAM), winter (JJA) and spring (SON) seasons (from DEA 2013)

Although some general tendencies are apparent for trends in both rainfall and temperature indices, there is some disagreement between studies. This can be attributed largely to two factors, namely the time period over which the data were analysed and the locations of the stations from which data were obtained. Large, naturally-occurring variations in climate at yearly and decadal timescales can greatly affect the calculation of trends, and thus it is important to consider the length of record when evaluating any trend analysis. Regional inferences based on individual stations are reliant on how representative a station or group of stations is of that area, and station data should thus be treated with caution. Some of the studies also rely on gridded products where station records have been interpolated in space onto a continuous surface. Such products should match closely the raw station data in places where the observational record is sufficient, but in data-sparse regions this information is less reliable, especially where strong environmental gradients exist. Details of the methods used to calculate trends also differ between studies, but these should rarely result in substantially different results.

1.2.3 Drivers of variability

Climate exhibits numerous modes of variability in global and hemispheric circulation patterns at intra-seasonal (of the order of 1 or 2 months) and inter-annual (year-to-year) timescales (see **Figure 1.14**). The El Niño-Southern Oscillation (ENSO) is recognised as the leading mode of inter-annual variability in the tropics and subtropics, and is driven by variations in sea surface temperatures (SSTs) in the equatorial Pacific Ocean. Links between ENSO and southern Africa's rainfall have been established such that warm ENSO events (El Niño) are commonly associated with below-average summer rainfall over much of South Africa and cold events (La Niña) are typified by above average rainfall in this region. It has been shown that severe summer drought in South Africa tends to occur under El Niño conditions (Lindesay 1988; Reason et al. 2000), a relationship that seems to have strengthened since the 1970s (Richard et al. 2000; 2001). Furthermore, seasonal prediction of summer rainfall in South Africa improves during strong ENSO phases (Landman & Beraki 2012). However, the relationship between ENSO

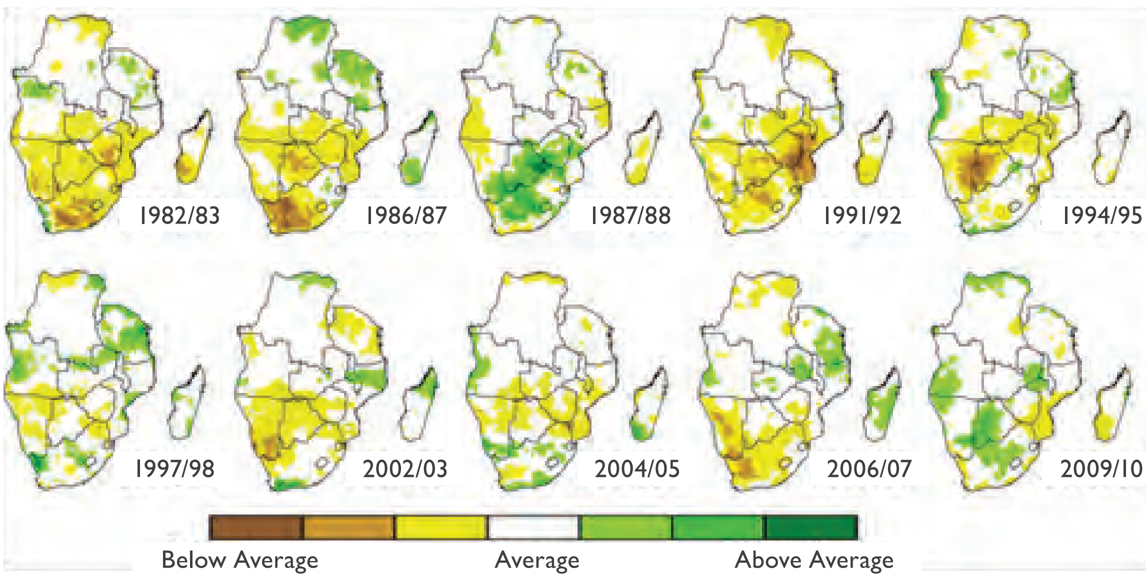


Figure 1.13: Rainfall anomalies recorded during a sequence of El Ninõ / La Nina conditions since 1980 (Source: FEWS NET 2014)

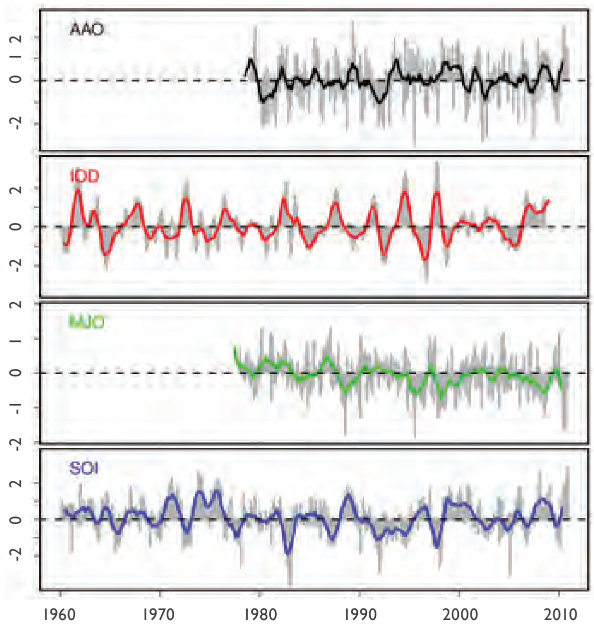


Figure 1.14: Time series of indices representing four major climate oscillations, namely the Antarctic Oscillation Index (AAO, top), the Indian Ocean Dipole Mode Index (IOD, second), the Madden-Julian Oscillation Index for 20 °E (MJO, third) and the Southern Oscillation Index (SOI, bottom), with the SOI being a representation of the El Ninõ-Southern Oscillation, the grey bars showing monthly values for each index and the solid curves being a 12-month running mean (from DEA 2013)

and rainfall in South Africa and the region is far more complex than a simple linear association and many factors influence the region's climate. For example, the frequency of synoptic scale patterns of convection over South Africa are modulated by ENSO events, but different synoptic regimes under the same ENSO phase can result in substantially different rainfall responses (Fauchereau et al. 2008). Complexities are also introduced through the influence of other climatic modes and interactions between these modes. As a consequence, there is considerable regional variability in rainfall anomalies associated with ENSO (**Figure 1.13**).

The second prominent inter-annual mode relevant for southern Africa is a dipole pattern in SST anomalies between the south-western and south-eastern Indian Ocean. A positive phase of this Indian Ocean Dipole (IOD; **Figure 1.14**), characterised by anomalously warm SSTs in the western part of the ocean, has been linked to increased summer rainfall over parts of southern Africa (Behera & Yamagata 2001; Hansingo & Reason 2008; Reason 2001). Increased SSTs in the south-western Indian Ocean have also been associated with an enhancement of the El Niño effect over South Africa (Richard et al. 2000). At an intra-seasonal time scale, the Madden-Julian Oscillation (MJO; **Figure 1.14**) has a noticeable impact on South African rainfall (Pohl et al. 2007). The MJO is an eastward propagation of large scale convective clusters in the tropics with a period of 30–60 days. It has been shown that convection over South Africa tends to be more strongly affected by the MJO during warm phases of ENSO and warm tropical Indian Ocean temperatures, such that intra-seasonal variability is higher and convection is less active during El Niño events (Pohl et al. 2007).

A further low frequency mode that is present in the mid-latitudes is the Antarctic Oscillation (AAO; **Figure 1.14**), which is defined by pressure anomalies between

Antarctica and the Southern Hemisphere mid-latitudes. A link is indicated between a positive phase of the AAO and enhanced rainfall over central SA, which tends to be stronger during La Niña years (Pohl et al. 2010). Particularly wet winters are associated with a negative phase of the AAO for the winter rainfall region of the southwest of the Western Cape Province (Reason & Rouault 2005).

Beyond the inter-annual timescale are decadal scale variations in climate which provide a slowly evolving background around which higher-frequency modes oscillate. For example, an approximately 18-year cycle in southern African rainfall has been identified in instrumental and proxy records extending back as far as 600 years (Tyson et al. 2002). It is not clear what causes this oscillation, but an "ENSO-like" multi-decadal pattern of variation has been identified at multiple periodicities (Reason & Rouault 2002). It is possible that interaction between phases of the multi-decadal and inter-annual variations act to enhance or mitigate regional responses (Kruger 1999; Reason & Rouault 2002). One component of the variability is associated with hemispheric circulation patterns (Malherbe et al. 2013b) that are statistically significantly associated with variability in tidal potential (Malherbe et al. 2014). In the context of the trend analysis presented in this study, it is very important to consider the possible influences of low-frequency variations, especially in rainfall, on the calculation of long term trends. It is also important to understand the drivers of the variability, to enable prediction at this very practical time scale.

Up until the intense El Niño of 2015/6, South Africa had not experienced serious ENSO related drought since 1991/2 (but recognising some adverse rainfall conditions in 2006/7). The globally damaging 1997/8 El Niño did not have adverse effects in southern Africa, although such effects were projected at the time. El Niño conditions in the eastern Pacific appeared to be developing in 2014, but did not eventuate, only to re-appear in 2015 and intensify to levels never before recorded. Early drought conditions in South Africa began to take hold during 2014, and at the time of writing (February 2016) were intensifying substantially, indicating a repeat of the ENSO-related drought intensities of 1991/2 and 1982/3. The 2015/6 drought conditions over large areas of South Africa indicate the vital importance of a better predictive understanding of these drivers.

1.2.4 Provincial trends

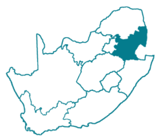
The results described in the preceding sections may be summarised on a provincial basis as follows:

Limpopo

- There is a mixed signal in the spatial patterns of rainfall trends for most seasons. However, for autumn (MAM) the majority of stations report rainfall decreases with significant reductions in the number of rainfall days. Reductions in the number of rainfall days are also evident for summer (DJF). Some of the stations showing reductions in rain days during summer also indicate increases in the 90th percentile of daily precipitation, which suggests a possible increase in the occurrence of intense rainfall events at these locations.
- Regional means show large inter-annual and decadal scale variability in rainfall indices, but once again point to significant reductions in the number of rain days (with associated increases in rainfall intensity) in summer and autumn.
- All but one station show significant increases in maximum temperature, with the strongest warming signal occurring in spring (SON). Minimum temperatures, however, experienced strongest warming in summer and winter (JJA). Spatial patterns for the daily temperature range are mixed and no region-wide trends are evident.
- Extremely hot days have increased significantly at all except one station in winter and spring, but trends

for the other months are weak. Extremely cold nights show general reductions in all seasons, but not all are statistically significant.

Mpumalanga



- There is a mixed signal in terms of changes in rainfall totals, with the trends being generally statistically insignificant. For autumn, some stations are reporting statistically significant reductions in rainfall. Rainfall days have been declining at most stations, annually and across all seasons, with the trends showing statistical significance. These changes imply an increase in the intensity of rainfall.
- Regional means show large inter-annual and decadal scale variability in rainfall indices, but significant reductions in rain days are evident for all seasons.
- Significant increases in maximum temperature have been observed for the seasons of autumn, winter and spring. The summertime increases do not exhibit statistical significance. Minimum temperatures have increased with statistical significance across all seasons. Spatial patterns for the daily temperature range are mixed and no region-wide trends are evident.
- Extremely hot days have increased significantly for winter and spring. Extremely cold nights show general reductions in all seasons.

KwaZulu-Natal

- Rainfall totals have been observed to decrease along the east coast, driven by statistically significant changes in the autumn rainfall totals. For the other seasons, mixed and statistically insignificant trends are reported in terms of rainfall totals.
- The number of rainfall days exhibit statistically significant decreases across all seasons and annually.
- The 90th percentile of daily rainfall totals also exhibit negative trends, particularly for the spring and summer seasons in the southern Drakensberg area.
- There is large temporal variability and no regional mean trends in rainfall indices, but stations suggest a spatially-coherent reduction in rainfall totals, rainfall days and 90th percentile of daily rainfall totals for autumn.
- Maximum and minimum temperatures have been increasing across all seasons, with the trends being statistically significant for all seasons except spring. Extremely hot days and extremely cold nights have been increasing consistently and decreasing, respectively.

Eastern Cape

- Trends in rainfall totals and the number of rainfall days are generally of a mixed signal and do not exhibit statistical significance. An exception is the most eastern parts of the province, where the number of rainfall days have been declining with statistical significance.
- Changes in the 90th percentile of precipitation are generally statistically insignificant.
- Temperature stations are confined to the southern part of the province, where both minimum and maximum temperatures have been increasing with statistical significance, annually and across all seasons.

Western Cape

- Trends in rainfall totals are generally not significant and show little spatial consistency across the province. Rainfall days, however, exhibit a fairly consistent and statistically significant decreasing signal along the southern coastal regions.
- Both maximum and minimum temperatures have been increasing significantly at most stations in all seasons, accompanied by increases in extremely hot days and decreases in extremely cold nights.

Northern Cape

- Station coverage is relatively sparse in this province, implying that regional means should be interpreted with caution.
- Trends in rainfall totals and the 90th percentile of daily rainfall are generally insignificant and exhibit little spatial consistency. However, there is evidence of spatially coherent increases in rainfall totals in the eastern parts of the province, with associated and statistically significant increases in the number of rainfall days in the eastern part of the province.
- Temperature stations are limited to the western part of the region, but all stations exhibit significant increases in maximum temperature and extremely hot days, for all seasons and annually. A large part of this warming can be attributed to persistently above-average temperatures in the last 10 years of the record.
- Increases in minimum temperature are generally weaker than those seen in maximum temperature, with stations in the far eastern parts of the province exhibiting decreasing trends in maximum temperature. As a result the daily temperature range has been increasing across the province.

Gauteng, Free State and North West

- There have been significant increases in rainfall over the western parts of the Free State and North West provinces, with changes over the three provinces being otherwise statistically insignificant.
- Some significant increases in rain days are apparent in the western part of the Free State and North West, but over Gauteng and the eastern parts of the Free State and North West these trends are negative.
- Temperature stations show strong increases in maximum temperature for all seasons and annually.
- Increases in minimum temperature are generally weaker than those seen in maximum temperature, resulting in generally increased daily temperature trends. In the western parts of the Free State and North West minimum temperatures are exhibiting upward trends.

1.2.5 Gaps and opportunities

Data gaps exist at continental and national level. These can be filled by seeking out records to add to both data sets. At continental level, the WMO could undertake the task of improving data availability, especially in regions that are under-represented. Together with this, an assessment of where new observations could be made would be of value, along with an assessment of how remote sensing can assist. Historical data preservation is critical before records degrade further. The same is true in South Africa, with SAWS potentially playing a critical role in quality control of data to establish an expanded high quality station set, with stations also at climatically sensitive locations and at remote and high altitude locations. Gathering data sets, ensuring quality control and making them available in near real time under a common platform would be valuable for research and application. Alignment of various monitoring efforts would be important – agricultural, ecological, the national energy utility and informal farm networks are all relevant potential sources of information. Statistical analysis and infilling could provide important new data sets to update the agro-hydrological database (Schulze 2008) that has provided an enormous amount of value thus far.

Understanding decadal variability and its drivers can afford the opportunity to make predictions that have a bearing on the 5–10 year time scale. This time scale is a very effective planning period in the fields of hydrology and agriculture. Existing datasets and modelling efforts can be tapped to provide greater insights for decadal variability while mitigation and adaptation strategies can be developed focussing on this timescale as well.

At climate change time scales, more information regarding trends and changes of weather systems important for South African climate variability can go a long way towards informing possible changes in extreme events in future (for example, Malherbe et al. 2013a). Large datasets of observed and modelled weather data can be applied to evaluate tendencies and these findings can be related to trends in impacts such as flood events, heatwaves and unseasonal frost.

1.2.6 Way Forward

South Africa would have an interest in supporting calls for the WMO to support African countries in data rescue and digitisation. SAWS could usefully conduct a process of identifying and auditing the various networks which collect weather data, so as to develop a strategy for increasing the number of reliable historical stations, and rationalise a larger core data set than is currently used in international reporting for future collection, together with remote sensing efforts. Such efforts would reduce the current uncertainty associated with provincial and finer scale synthesis and detection of climate trends. Co-ordination by SAWS and ARC with national research infrastructure efforts such as those of the South African Environmental Observation Network (SAEON), which is installing automatic weather stations in remote sites, and especially at high altitudes, would add value to a co-ordinated national network.

1.3 Co-ordinating Climate Change Research and Data Dissemination in South Africa

The co-ordination of climate change related research in South Africa has improved markedly during the past five to ten years. This is largely due to a number of national and regional initiatives. The National Research Foundation (NRF) / Department of Science and Technology (DST) developed the 10 year Global Change Grand Challenge in the 2000s, to be based on its Global Change Research Plan (GCRP). The GCRP is strongly promoting cross-institutional and multi-disciplinary research through the Applied Centre for Climate and Earth System Studies (ACCESS) as well as through the South African Risk and Vulnerability Atlas (SARVA). Under mandate of the NCCRWP White Paper, the DEA's LTAS was an invaluable endeavour which consolidated climate change projection and applied climate change research done in South Africa to the development of a number of valuable technical reports in 2014 and 2015. With the growing national co-ordination of research capacity, better guidance is also available for internationally funded initiatives. The most recent example is the establishment of the Southern African Science Service Centre for Climate Change and Adaptive Land Use (SASSCAL), which promotes collaboration in climate change research between South Africa, Namibia, Botswana, Zambia and Angola. The national research, monitoring, synthesis and dissemination effort stands to be catalysed by significant increases in national connectivity via the South African National Research Network (SANReN; www.sanren.ac.za/overview), providing major opportunities for nationally linked research infrastructure such as the Meraka Institute and the National High Performance Computing Centre.

With respect to research dissemination the three key issues are timeliness, credibility and accessibility.

- Timeliness relates to the lead time between information release and the potential use of that information.
- Credibility relates to the appropriate use of risk or uncertainty language that does not diminish the usefulness of information released.
- Accessibility relates to a wide range of issues from message comprehensibility and medium (visual / graphic / text) to the physical form of communication, be it electronic or otherwise. Accessibility issues also include fragmentation of communication, which has increasingly become important with the rise of smart device connectivity and a proliferation of specialist information providers at national to international levels.

There is a substantial literature dealing with these issues, and several best practice studies and experiences are available to inform how dissemination could be optimised. It would seem appropriate for SAWS to provide a critical entry point for overall information provision, as defined by the National Framework for Climate Services (GFCS SA, 2013), but that this service needs to link mutually as directly as possible with the other national providers such as universities and various national and provincial entities. With respect to longer term projections of climate change risk, SARVA appears to provide the required role. However, it is important that SAWS plays a critical role in ensuring alignment with longer term messages disseminated internationally through its links to the WMO.

A wide set of information products is currently being produced and is available in various forms, including the SAWS monthly state of climate bulletin, SAWS monthly drought updates, the Agricultural Research Council's *The Watchman* and agricultural journals, the DAFF early warning system that has a dissemination channel via DAFF extension officers, the DST / NRF, SARVA, the Climate Systems Analysis Group (CSAG) at UCT's climate information portal, the South African National Space Agency's (SANSA's) initiatives such as Crop Watch for South Africa, and the Water Research Commission's (WRC's) scientific and report products, including *The Water Wheel*. Finally, the National Framework for Climate Services provides a structure for consulting on and implementing a better co-ordination of the generation and dissemination of these and other products.

One of the major routes for increasing access to state-generated information is via strong NGO interface roles and other "boundary organisations" such as the African Climate and Development Initiative (ACDI; http://www.acdi.uct.ac.za/). These include government-NGO-business communication channels via programmes such as those of the World Wide Fund for Nature South Africa (WWF-SA; http://www.wwf.org.za/) and the Adaptation Network (http://www.adaptationnetwork.org.za/) that catalyse the dissemination of climate information into the user community.

1.4 Key Messages

There is no evidence to suggest a slowing of anthropogenic climate change trends in South Africa since 2000. Temperature trends consistent with anthropogenic warming continue to be seen across South Africa, with the strongest trends in the west and east, but less so in the central interior. Average rainfall trends are ambiguous, but evidence for longer dry spells, fewer rain days and more intense rainfall events is mounting. The impact of decadal variability on rainfall remains a significant concern, with the El Niño drought conditions of 2015/6 causing adverse impacts on South African socio-economic conditions through effects, at minimum, on the water and agriculture sectors. Under La Niña conditions during the decade of the 2000s, significant flooding events were common. The increasing severity of drought and flooding conditions suggest an interaction between, and an intensification of, rainfall extremes due to natural variability and anthropogenic climate change.


Weather monitoring device

Model projections suggest significant warming and rainfall change for South Africa over several decades, even under strong international mitigation scenarios. Local warming of several degrees by mid-century is virtually certain, and rainfall variability is very likely to increase, but the direction and amount of rainfall change cannot yet be projected with confidence.

A stronger national focus on, and investment in, the observation network will be important for quantifying local to national patterns of climate change, with an urgent need for more detailed information about atmospheric pressure profiles, temperature, rainfall, wind, humidity and evaporation. High altitude sites require a particular focus because of their influence on temperature and especially orographic rainfall, and hence runoff, which then cascades down to lower altitudes. In addition to weather data gathering and quality control, the hydro-climatic record since 2000 should be brought to the same level of quality and spatial resolution as the WRC's 1950–99 climatology, and hence hydrology, datasets (Schulze et al. 2005), and they should be maintained at this level of excellence in order to inform government positions on climate change impacts, adaptation and mitigation on a continual basis.

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2. CLIMATE CHANGE RISKS, IMPACTS AND VULNERABILITIES

2.1 National Circumstances

South Africa is a middle income country, but with one of the highest levels of socio-economic inequality in the world. South Africa's annual GDP is roughly R4 trillion (in the financial year 2015, StatsSA 2015), with an annual growth rate in recent years of about 2%, although lower since 2011, and a negative current account balance of about 5% of GDP (third quarter 2015). South Africa is the dominant economy within the southern African region, and shares borders with Botswana, Lesotho, Mozambique, Namibia, Swaziland and Zimbabwe. Energy is exported to Namibia, and water is imported from Lesotho, with the major Limpopo river system being shared with Botswana, Mozambique and Zimbabwe, and the Orange River with Lesotho and Namibia. The economy of the country is responsive to changing demand for raw materials, which affects the exchange rate, and thus purchasing power for imported food and energy and the resulting balance of payments.

Climatically, South Africa may be classed as a dry, warm country in international terms, but in a regional context it is less warm than its northern neighbours, and enjoys much higher and more reliable winter season rainfall than its neighbours in its winter- and all-year rainfall south-western and southern reaches, a more reliable summer rainfall than Namibia and Botswana, but less annual rain than many parts of Zimbabwe and Mozambique. The region as a whole is sensitive to the El Niño-Southern Oscillation (ENSO) driven dry and wet spells, with El Niño climate states tending to reduce rainfall across most of the region, and La Niña conditions increasing rainfall relative to the long term average. Currently (namely 2015/6), South Africa is experiencing the adverse effects of the strongest El Niño on recent record, with two successive seasons of below average rainfall recorded in many parts of the country.

South Africa's population is now above 50 million people, but with a declining fertility rate, and a rapidly urbanising population, leading to growth in informal settlements near most established urban centres around the country, and to a disrupted social structure both in these settings and in the rural regions which are donating younger, economically active people to the cities and towns. As a consequence, human health indicators have declined since 1990, but have seen some improvements as a result of a focus on the Millennium Development Goals (MDGs). On the whole the Human Development Index has declined since the 1990s.

Taken together, while South Africa's transition to democracy has decreased levels of extreme poverty and improved international relations and trade, its exposure to demand driven raw material export earnings has increased vulnerability. South Africa is, however, estimated to have among the highest resilience to climate change in the southern African region owing to its relative wealth and high adaptive capacity (Midgley et al. 2011a). It is noteworthy that there are strong links between academic capacity and policy makers in the area of climate change, and that this allows scientific findings to be considered rapidly for integration into planning and policy making, as appropriate.

Polluting the air

2.2 Climate Change as a Stress Multiplier

In its Fifth Assessment Report, Working Group 2 of the IPCC (IPCC 2014) highlighted prominently a framing of climate change as an additional stress that interacts with a complexity of existing stresses in human societies. This framing provides important practical insights that include (for example, Ziervogel & Taylor 2008):

- providing a clear local context in which climate stresses have impacts
- the identification of current vulnerabilities that are likely to be exacerbated by climate change (thereby allowing better prioritisation of adaptation options)
- a strong mandate for appropriate information gathering at the relevant scale

This perspective encourages stakeholder engagement (Vogel et al. 2007) to ensure that adaptation planning and implementation can be well justified and locally supported.

One of the important signals of local vulnerability to climate change is the so-called "adaptation deficit", a phrase that describes adaptations that should already have been effected as a result of damages due to current levels of climate variability such as drought, heat waves, wild fires, flooding or high tide storm surge events, even before having to adapt to the projected consequences of climate change. South Africa has suffered significant damages due to such events over the past decade, amounting to at least ZAR 1 billion annually (2010 ZAR value), and likely up to twice that amount (DEA 2011b). The adaptation deficit as identified by damage costs due to extreme events is an important guide for potential investment in adaptation action.

The stress multiplier framing is also highly relevant for analysis at higher spatial scales than the local and national scales. It is essential for South Africa to understand and quantify vulnerability to climate shocks that act as stress multipliers at the international level. The reason for this is the increasing globalisation over the past few decades, and new interdependencies, such as those between food and biofuel production, that have created complex chains of vulnerability across regions and the globe. Destabilisation of communities by extreme drought conditions, for example, has been shown to drive human migration that can extend across national borders and result in profound political effects. Current impacts of extreme events are important opportunities for learning about the way in which future climate change can interact to exacerbate existing stress conditions, such as inadequate housing, inadequate service delivery and lack of maintenance of infrastructure.

2.3 Analysis of Interdependencies

Integrated assessment modelling tools have increasingly become available for application in a South African and southern African setting. Prior to their recent application, climate risks were usually assessed sector by sector, with some efforts to overlay multiple risk, impact and vulnerability criteria using spatial overlay methods (for example, Midgley et al. 2011a). Integrated assessments are quantitative approaches for analysing climate change impacts that take into account interdependencies between sectors (through explicit networks or chains of responses) and the role of economic responses in amplifying or reducing risk. They are useful tools for formalising narrative-type approaches. Such narrative-style approaches may be more accessible to stakeholders and retain advantages due to being more intuitive, open-ended and inclusive of non-specialists.

There are many ways in which interdependent response chains or networks can be conceptualised in integrated assessment approaches and formalised into a modelling framework, each of which is likely to produce a picture that is incomplete in at least some ways. For this reason, it is valuable to consider the results of several approaches to build an overall view of integrated risks, in a similar way to that in which multiple climate models are considered when producing future climate projections.

Three main approaches are described in this report, namely:

- the quantitative United Nations University-Wider approach (UNU-Wider)
- the quantitative Bureau for Food and Agricultural Policy (BFAP) approach
- the narrative LTAS approach

Each of these provides a useful insight into so-called "impact channels", with either formal quantitative or narrative qualitative development of how effects are propagated across the economy, providing useful insights into points of intervention for most cost-effective adaptive responses. At this point in time the quantitative methods provide potential for assessing the cost effectiveness of a range of adaptation responses. All of the approaches incorporate international effects that may themselves be responding to climate change impacts. These international effects can be significant for local adaptive responses if they result in strong price signals – a factor that is important in the agricultural and food sectors, for example, where strong international price signals one way or the other can encourage or discourage local production.

- **The UNU-Wider Approach** (Theresa et al. 2015) is based on the Systematic Assessment of Climate Resilient Development (SACRED) tool, which in South Africa is coupled to an economic general equilibrium (GE) model that represents the South African economy in 2002. The main impact channels considered operate via water resources which, in turn, are allocated to agricultural production, industrial and urban use (including for energy production), and via rainfall related impacts on the road transport network. Finally, sea level rise effects are modelled via land inundation estimates. Several modules of the SACRED modelling framework have been replaced by locally developed modules for South African impact assessment, further increasing the local relevance of this approach. Climate change effects on the water resource impact channels are fed through to the GE model, allowing the economy to respond and adjust, and for a final impact on sectoral and national GDP to be calculated. The tool accounts simultaneously for climate change effects on the international economy via effects on economic signals such as commodity prices.
- **The BFAP Approach** (Strauss et al. 2008) has the agricultural and food commodity sectors at the core of the approach. A partial equilibrium model covering 52 agricultural commodities has been formalised, with demand and supply modelled for each, allowing an equilibrium to be achieved in which demand and supply balance at the national level. The model employs a closed system of 24 equations representing relevant impact channels. For example, grain production is linked to livestock production through feed availability and price, with the net result being that a disruption in the livestock sector would translate to the supply and price of grains and oilseeds, and vice versa. This approach is also able to take account of global markets via data from major markets in the USA and Europe.
- **The LTAS Approach** (DEA 2015a) defines a network of impact chains (termed "systemic impact pathways") and employs a narrative qualitative approach under a set of three future climate scenarios to explore which elements of the network of impact chains would be most relevant. The approach recognises that South Africa's development pathway would be a critical element of its future climate vulnerability, and defines two major scenarios, namely:
    - an unmitigated scenario with limited global efforts to decarbonise the economy
    - a mitigated scenario according with significant global action to limit emissions and decarbonise the economy

These development scenarios could be linked with three main climate scenarios, two warmer climate scenarios aligned with the mitigated future development pathway, and a hotter climate scenario aligned with the unmitigated future pathway.

Taken together, these three approaches identify extremely important interdependencies that help to propagate effects across the socio-economic fabric of South Africa. Water and food security emerge as vital issues for developing a robust adaptation response in the country, but important interactions with socio-economic development and some sub-national interactions are identified as well. The econometric approaches generally find that the economy of South Africa acts, to an extent, like a natural adaptation mechanism through adjusting prices. This leads to changing demand / supply balances that encourage optimal allocation of resources such as labour, finance, land and other assets. These allocation adjustments may occur rapidly in the econometric models, which is unrealistic in the real world.

The resulting economically-based models estimate quite modest impacts on GDP at national scale by mid-century, but sub-national impacts on sensitive and vulnerable sectors can be seen, especially in the rainfed agricultural sector. The assumption of rapid resource re-allocation is almost certainly always violated, and thus the actual impacts are likely to be more extreme than those simulated. What the models do suggest is that for effective adaptation, a major interdependency will emerge between the ability to re-allocate labour and financial resources. In other words, an inflexible labour force and financial investment strategy could constrain economically driven adaptation. This suggests that if one of the results of technology transfer arrangements under the UNFCCC is increased mechanisation for adaptation purposes, then there are implications for South Africa's labour force.

2.4 Observed Risks, Impacts and Vulnerabilities

While the international scientific community has generated a significant amount of information on observed risks, impacts and vulnerabilities (RIV) as a result of climate change, this topic remains a major gap at the national South African and regional southern African levels. The most comprehensive summary on observed risks, impact and vulnerability is found in the recent IPCC 5th Assessment Report (IPCC 2014). In South Africa, there is increasingly effective synthesis and communication of observed climatic conditions risks, their recent trends, and their impacts conducted by the South African Weather Service (SAWS) and the National Disaster Management Centre (NDMC). In addition, several national scientific facilities and institutes gather data on trends in climate-affected sectors. The South African Environmental Observation Network (SAEON) is rolling out a national network of observation nodes that act as foci for SAEON scientists and collaborators to put in place long term monitoring of a range of environmental variables and, increasingly, social variables (SAEON 2016). Most medical facilities collect a range of data on human well-being and health trends, and engagements are underway between the Department of Environmental Affairs and the Department of Health to maximise opportunities for analysis of these data.

Universities do not frequently conduct studies to monitor long term trends, but two good examples include the Wits Rural Facility (Wits Rural Facility 2016) which has gathered data on social well-being in a rural poor setting since the early 1990s, and the South African Bird Atlas Project (SABAP 2016) which has gathered data since the late 1980s on observed changes in abundance of wild bird species. Many data are gathered by several industries including the insurance industry, agriculture and likely several others. Unfortunately these are not always freely available for analysis and synthesis. As a result, South Africa does not yet have an integrated view of these trends but there is great potential for doing so, and for integrating this through a national system such as the South African Risk and Vulnerability Atlas (SARVA 2016).

2.4.1 Observed risks, impacts and vulnerabilities due to long term climatic change

Historically, there have been relatively few co-ordinated national efforts to gather systematic observational data about environmental and socio-economic responses to long term climate trends other than for climate data itself. The few exceptions include monitoring of marine stocks and sea birds, agricultural and forestry production


Arid landscape

and associated environmental trends (such as mountain catchment water yield data), elements of human health, water quality, and biodiversity monitoring, with the outstanding example being wild birds, involving thousands of volunteer "citizen scientists" (see SABAP 2016). These efforts are complicated by natural variability which, in the agricultural sector especially, reveals sensitivity of production to rainfall variability.

As a result, South Africa has few demonstrable examples of adverse (or otherwise) impacts due to long term trends in climate. The most comprehensive analyses have been carried out in natural and semi-natural terrestrial and marine ecosystems, with both showing some trends but also revealing substantial complexity which makes attribution to any single cause a challenge.

This situation has improved substantially with the launch of the South African Environmental Observation Network (SAEON) and the South African Risk and Vulnerability Atlas (SARVA). SAEON is both developing new monitoring platforms and sites while also re-invigorating historical efforts that had suffered a period of neglect, the most noteworthy being long term water yield monitoring from mountain catchments at sites such as Jonkershoek in the Western Cape and Cathedral Peak in the KwaZulu-Natal Drakensberg. SAEON is building an environmental observation network encompassing a wide range of variables, including the potential for incorporating socio-economic trend data. SARVA provides a platform for the integrated reporting of trends, and allows data integration, synthesis and enhanced accessibility to user communities.

The most convincing evidence emerging for long term climate change impacts thus far is for increased coral reef bleaching in the tropical coastal waters of northern KwaZulu-Natal (Celliers & Schleyer 2002), some shifts in the geographic ranges and / or timing of migration in migrating wild birds (Altwegg et al. 2011) and in coastal marine fish species (Whitfield & Elliot 2002). Increasing encroachment of woody vegetation (shrub and bush encroachment), possibly enhanced by CO_2 fertilisation of shrub and tree growth (Buitenwerf et al. 2012), has been strongly implicated as a long term anthropogenically driven trend in ecosystem structure and function that could have major hydrological, livelihood, and biodiversity impacts.

In the agricultural sector, crops sensitive to temperature signals may have shown early responses, but these appear to have been addressed by adaptive responses by the producers. An example of this is export fruit crops sensitive to chilling requirements and sunburn where early signs of impact have prompted farmers to respond by employing technology such as shade netting and evaporative cooling, or shifting to alternative crops.

2.4.2 Observed risk, impact and vulnerability due to extreme events

Climatic observations from around the world suggest that there may be an increase in some forms of extreme events, with a somewhat greater chance today of heat waves and flood events than previously observed. In South Africa, the same trend has been found, with heat wave conditions found to be more likely, dry spell duration slightly lengthened and rainfall intensity increasing. However, it must be noted that South Africa has largely avoided adverse effects of El Niño conditions since 1991/2. The past two decades therefore represent a period of above-average rainfall that has prevented extreme drought conditions from manifesting themselves in South Africa and the region. As a result, flooding and storm conditions featured more prominently as extreme event issues than drought until 2014.

South Africa's Second National Communication under the UNFCCC (DEA 2011b) calculated impacts due to extreme events in South Africa, and found these to be approximately ZAR 1 billion per annum for the period 2000–9, although it was estimated these could be around twice as high due to under-reporting. Since then, the NDMC and its provincial nodes have begun gathering and reporting data on the economic and financial impacts of extreme events. Data on a wide range of impacts are available for at least three provinces, namely, the Western Cape, Mpumalanga and KwaZulu-Natal.

The data sets available for this report reveal clearly a shift from extreme high rainfall and storm related events to drought events from 2010 to 2015. Reported drought disaster data are more directly related to annual weather reports by SAWS to the WMO. Storm and flooding-related disasters for most regions are reported in narrative form by SAWS. High temperature events are often indicated by reported wild fire events. The NDMC has also been developing indicative risk profiles for different hazards at national level. These can be used to analyse links with extreme events.

If NDMC provincial reports are combined, these show clearly where large extreme events have affected multiple regions of the country, but more complete recording would assist in providing a much clearer picture. It is not clear whether a lack of disaster reporting is due to higher resilience in some areas, or if it is simply due to incomplete data capture – it would be very valuable to policy makers to be able to discern this.

Annual anomaly data for temperature and rainfall as reported by SAWS are indicators of extreme event incidence, especially in the form of drought. Improvements would result if extreme high rainfall and storm events were to be captured in the form of shorter duration anomalies and mapped, if possible, while accumulative drought indexes that incorporate heat stress would be valuable in addition to rainfall anomalies.

2.5 Future Risks, Impacts and Vulnerabilities

South African and international scientists have been producing projections of future risks due to climate change in a wide range of sectors since the first studies conducted in the early 1990s. These have been facilitated by very good access to spatially explicit climate information, both in terms of past trends and future projections. Nonetheless, it remains challenging to achieve a clear picture of potential risks due both to the uncertainty surrounding especially projected rainfall changes, and due to a lack of standardised approaches for impacts modelling.

The most recent attempts to derive a commonly understood set of climate projections for risk assessment, as part of South Africa's LTAS process, did not narrow the range of uncertainty in the rainfall projections, although the median projection remains for a drying trend in the western and south-western regions of South Africa, and a wetting trend in the eastern seaboard and north-eastern interior – an understanding that has been in place since the development of South Africa's Second National Communication under the UNFCCC. As a consequence, there is a very wide range of risks to be considered, especially for the medium term (namely, over the next three decades).

Three distinct approaches have been followed to deal with this challenge:

- The first is to focus on summary scenarios representing both drier and wetter futures (DEA 2015a).
- The second is to represent the full range of climate change projections to produce so-called "probability density functions" of future risks (UNU-Wider SACRED approach).
- The third is to select specific climate scenarios especially when the process of running impacts models is challenging and expensive (commonly used in sector-specific impacts assessment efforts such as the biodiversity and agriculture sectors).

All of these approaches offer value of some kind, but the challenge is to be able to synthesise from them a core message of likely risk.

A further important consideration for risk assessment is the contrast between sector- or process-specific projections of risk, versus integrated assessments, including inter-sectoral interactions and feedback effects from the economy. South Africa has only recently begun to employ these approaches, as pointed out in **Section 2.3** above, and they are providing a valuable additional window onto the risk landscape and potential for adaptation interventions.

2.5.1 Future risks due to long term change

Risks due to long term climate change in South Africa have been extensively modelled, but with a strong bias towards certain sectors and not others. The main climatic drivers whose sectoral impacts have been modelled are temperature and rainfall, with most efforts using averaged projected changes, and less frequently changes in extremes, to simulate responses. The most recent review of this field in South Africa (Ziervogel et al. 2014) highlighted five sectors best covered by assessments of future climate change risk, namely:

- hydrology and water resources
- biodiversity
- agriculture and forestry
- human settlements
- human health

Climate impacts modelling of hydrological responses, biodiversity and ecosystem responses, and some areas of crop responses are the most mature fields of work in South Africa (see DEA 2011b). Other sectors that have received some attention include marine ecosystems and fisheries, but these are complicated by the interaction between climate and oceanic changes that are less studied and possibly even more uncertain at this point in time than rainfall projections. In addition to this sector bias, there has also been a sub-national bias, with efforts more developed for the Western Cape, Gauteng and KwaZulu-Natal provinces than for other provinces, and with a particular focus on the main urban centres.

2.5.1.1 Hydrology and water resources

Climate change impacts assessment in the water sector in South Africa is very well served by several decades of research, and potential adaptation responses by many decades of water resource planning as a response to variable rainfall and hence water supply. Significant investments in hydrological science in this country have made possible powerful national databases of climatic, hydrological and soil water information at high spatial resolution and at daily time steps from which trends over the five decades spanning 1950–99 may be assessed. However, information at this level of detail terminates in the year 2000 (Schulze et al. 2010), and while climate data exist for subsequent years, it is not readily accessible in similar quality controlled form.

A major report on climate change impacts on hydrology in South Africa was produced in 2011 (Schulze 2012), projecting impacts on an exhaustive set of hydrological measures. Among these, important projections were made on the future responses of societally relevant hydrological behaviours such as stormflows and drought. Stormflow changes were projected to display a distinct west to east pattern, with western coastal regions showing reduced stormflows by mid-century. However, an abrupt shift to increased stormflows was projected in the transitional rainfall zone between the winter and summer rainfall zones (**Figure 2.1**). Hydrological droughts were simulated to show a similar spatial pattern for both summer and winter rainfall zones, showing an increasing frequency of mild, intermediate and severe drought conditions by mid-century for winter rainfall zones, and decreased frequencies for the summer rainfall zones.

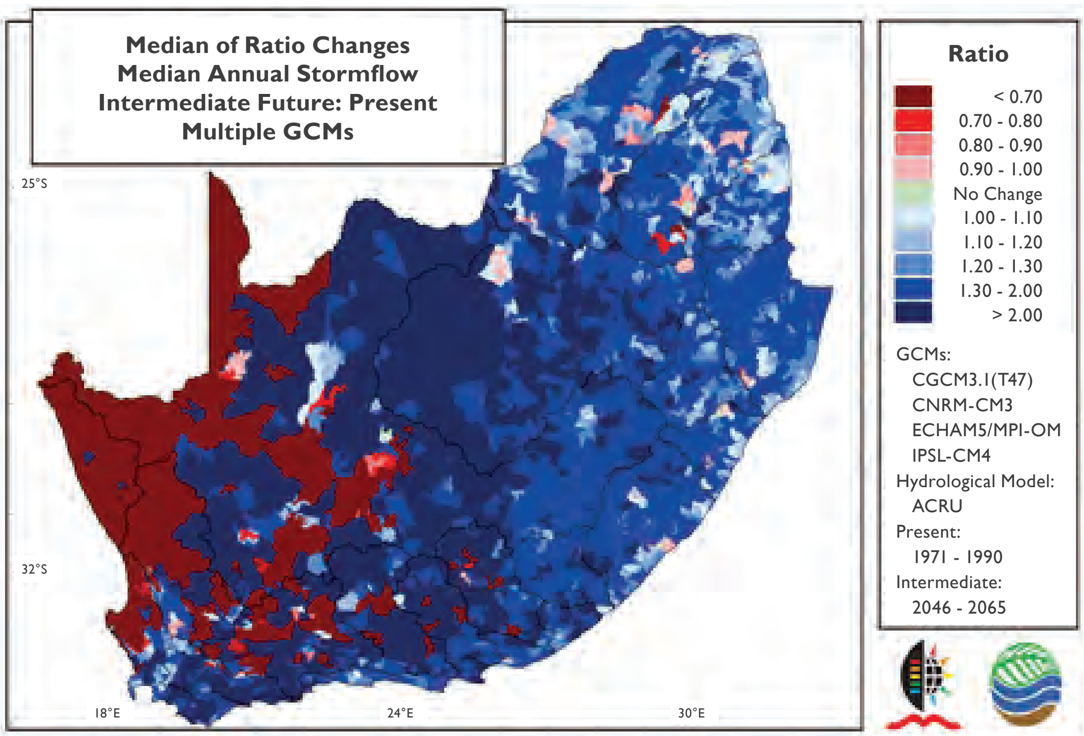

Figure 2.1: Medians of ratio changes of median annual stormflows by mid-century, derived with the Agricultural Catchments Research Unit (ACRU) model from output of multiple global climate models (GCMs) (Schulze 2012)

Models of lower spatial and temporal resolution have made possible rapid assessments of impacts and vulnerability using a wide range of climatic modelling inputs (Cullis et al. 2011). This technology has also allowed the translation of downscaled climatic information into hydrological terms for direct use in assessing water resource impacts, and for related effects on water-dependent sectors. The fundamental nature of these models allows extrapolation of results to novel climatic conditions (which is a significant limitation for assessments in several other sectors).

All sectors of South Africa's economy would be affected by any appreciable change in water supply, and in particular this would affect the current balance between urban / industrial, and agricultural demands for this key resource. Current policy aims for an assurance of water supply for urban and industrial use of 98%, but somewhat lower for agricultural use. The availability of surface water is determined by rainfall, but is amplified relative to rainfall variability by a factor of 2–5 times (Schulze 2000). Variability in surface water reduces the usable yield (amount of surface water that can be stored for reliable and sustained supply) to only about 20% of South Africa's mean annual runoff of ~ 49 000 million m^3 (DWAF 2004). More than 95% of the stored surface water yield is allocated for domestic, industrial and agricultural use, the ecological reserve (namely, that fraction of water required for the ecological functioning of rivers), and to meet international obligations. Groundwater currently accounts for only 9% of water use in South Africa. National demand for water is projected to increase by 32% by 2030 due to population growth and ongoing industrial development, including electricity generation (van Rooyen et al. 2009). The National Water Resource Strategy (DWA 2013) has taken initial steps to account for potential climate change impacts over the time frame relevant to the strategy.

Despite the sophistication available to this sector in terms of modelling technology, the wide uncertainty in rainfall projections does not permit a clear and specific message on future climate change effects on water resources (see DEA 2013a). Previous analyses have indicated a wide range of potential outcomes, both wetting and drying, due to uncertainty in rainfall projections. Projected temperature increases are more certain, and will partially reduce effective rainfall, because of an increase in potential evaporation of about 5% per 1 °C (Schulze 2011). As a result, a general increase of evapotranspiration by ~ 5–15% is projected under unmitigated emissions scenarios, with lower increases projected for coastal regions and higher increases for the interior. This outcome strongly tends to decrease the frequency of soil moisture conditions suitable for crop production over much of the country, except if this is offset by projected increases in rainfall that are sufficient to compensate. Such conditions have a roughly 50% chance of occurring according to the LTAS summary projections (DEA 2013a).

Overall, taking into account rainfall projection uncertainty together with a tendency for more variable rainfall to occur, more variable river flow is projected over much of South Africa, with a potential increase in the frequency of both dry spells and rainfall intensity, and related effects on flooding and groundwater recharge events. The spatial pattern and time course of these projected changes depends on the climate models used, the specific emissions scenario, and the method of downscaling the data to a locally relevant scale. Under the median climate scenario for mid-century, a decrease in river flows of up to 30% is projected for most of the western regions of the country, but for the eastern seaboard and interior coastal plain and Drakensberg uplands, an increase in river flows of up to 100% is projected by mid-century.

Such uncertainty leaves two main options for risk assessment. The first is a full assessment of the widest plausible range of hydrological change, and the second is an analysis starting from an analysis of current vulnerability and future development need, rather than from the future rainfall scenario. Both approaches have recently been followed.

Using a very wide range of future climate scenarios in the SACRED modelling framework (DEA 2013a), a picture of national runoff change emerges that spans from a 20%

decrease to a 60% increase by as early as 2050 under an unmitigated emissions pathway. The value of this approach for assessing mitigation benefits is obvious when comparison is made between the projected range of changes under a constrained emissions scenario, which narrows the projected change to between a 5% decrease to a 20% increase in national annual runoff. When this approach is repeated at sub-national scale, it confirms the overall median rainfall change pattern, with the eastern seaboard and central interior of the country showing a tendency towards runoff increases, but with the northern and western Cape showing decreases in runoff.

The LTAS approach on water and hydrology suggested an assessment approach based on current resilience of water supply that is quantified by so-called reconciliation studies that support water resource planning nationally, provincially and at municipal level. South Africa has developed sophisticated methods of accounting for historical water resource variability to guide infrastructure planning. This would provide a valuable basis for future climate change risk assessments.

In one example for a rural municipality, a rainfall reduction of 8% reduces projected volumes of ground and surface water by factors of 31% and 30% respectively. This raises the cost of meeting water demand by three times what would be required under normal climate conditions because of the greater expense in securing new water resources (Mukheibir 2009).

According to Ziervogel et al. (2014), water resources impact assessments have begun to consider finer spatial and temporal details such as the changes in the timing of flows, extreme hydrological events, and issues of land use and land cover change. They state that "complexities of the hydrological cycle, influences of land use and management and the linkages to society, health, and the economy indicate far higher levels of complexity in the water resources sector than in other sectors" (Ziervogel et al. 2014, 609). As the focus becomes more detailed, water quality responses to climate change are emerging as a new focus, with assessments addressing issues of sediment yield due to land use practices, effects of water temperature and non-point source pollution.

Finally, at local scales, the consideration of interactive sectoral relationships is now being considered in so-called "nexus" studies, often with water as a central pillar. A good example is the "Food-Energy-Water Nexus" (Von Borman & Gulati 2014) or the even more transdisciplinary "Food-Energy-Water-Land-Biodiversity Nexus" studies (Midgley et al. 2014), the latter carried out in the Western Cape. This approach shows great potential for providing an interdisciplinary framework for more deliberately integrated climate change impact assessments.

2.5.1.2 Biodiversity

Modelling of biodiversity and ecosystem responses to climate change has evolved significantly since its inception during the 1990s, and South African scientists have been among the world leaders in aspects of this field. Availability of key data sets for iconic species or plant and animal groups, together with exceptional understanding of the climatic and other controls of ecosystem function and structure developed over decades, have allowed biologists to cope to some extent with the challenge of extremely high biodiversity and complex ecosystem processes.

Early projections made based on climate projections of the 1990s indicated high projected risk to the unique and species-rich biomes of the south-western region of the country, including high risk of species extinctions, especially of plants (DEA 2011b). Advances in biodiversity and ecosystem process-based modelling, together with availability of updated climate scenarios has changed this picture. The current view is that, for the wetter and lower level warming climate scenarios for mid-century, there are relatively minor impacts on the biodiversity of most SA ecosystems, but risks rise substantially for hotter and drier scenarios. Much depends on the response of the South African climate to global warming and the effectiveness of global mitigation efforts.

However, it is important to note that significant ecosystem structural change is being driven by so-called bush encroachment (woody thickening) in many parts of the eastern seaboard, eastern inland and north-eastern regions of the country, and that this can be attributed, to some extent at least, to the direct fertilising effects of rising atmospheric CO_2 levels (Buitenwerf et al. 2012). Projections based on this understanding, and applying mechanistic modelling, suggest that this process could continue and result in the conversion of significant areas to bush rather than open grassland or woodland vegetation. These projections have implications for hydrological responses, albedo and local climatic feedback effects, carbon sequestration and strong adverse effects on the biodiversity that depends on open ecosystems (Midgley & Bond 2015).

In order to develop insights beyond those of conservation interests, integrated assessment approaches are needed to enhance relevance for policy formulation and implementation related to land use and infrastructure planning, as well as for investment decision making. Under hotter and drier future climate scenarios, some significant adverse impacts have been projected for a wide range of South African biomes, with a likely encroachment of desert-like conditions into the north-western regions of South Africa, and the contraction of the Succulent Karoo and Nama Karoo biomes that are currently dominant there. Recent observational work is also showing the westward spread of fire-carrying grasses into the eastern reaches of the currently fire-free Nama Karoo Biome, with significant implications for land use and disturbance management in those regions.

The development of this observational and modelling work has positioned South African researchers well to make significant contributions to models of atmospheric CO_2 impacts on vegetation structure and function, disturbance management and resulting land use and conservation management. Supported by activities of SAEON and the South African National Biodiversity Institute (SANBI), South Africa is well positioned to develop and implement adaptation plans and to support an agenda incorporating ecosystem-based adaptation approaches, which incorporate the resilience of natural ecosystems to increase societal adaptive capacity to climate change.

2.5.1.3 Agriculture and forestry

Efforts on risk assessment in the agricultural sector date from the late 1990s, and have often been conducted within an agro-hydrological framework, with useful inferences for downstream impacts including water quality outcomes (see summary in Schulze 2012). Since these first studies, an increasing amount of work has been done on conducting assessments of a wide range of staple crops, such as maize, sugarcane and wheat, on high value export commodities such as horticultural crops, and on plantation forest species using a range of modelling approaches. The most frequently used approaches have included:

- Point-based process models, including the internationally developed Decision Support System for Agrotechnology Transfer (DSSAT), the Agricultural Production Systems Simulator (APSIM; for example, Crespo et al. 2011) and the FAO's AquaCrop Model (for example, Heng et al. 2009);
- Expert-constructed and / or data-driven "key limiting factor" models that link crop production to controlling climate variables (often embedded within hydrological models and linked to national spatial climate databases (for example, Schulze 2011). These approaches have also been used for pest and disease modelling, including the sugarcane pest, Eldana, and the fruit pest, codling moth (Schulze 2011).
- Rule-based "climate envelope" models (for example, with thresholds for a range of field crops, pastures, horticultural crops, tree species) developed by Smith (2006) which, when linked to spatial databases and GCM output can estimate spatial shifts in the climatic suitability of target crops (for example, Schulze 2011)
- Correlative models that use established relationships between historical production / growth and climatic

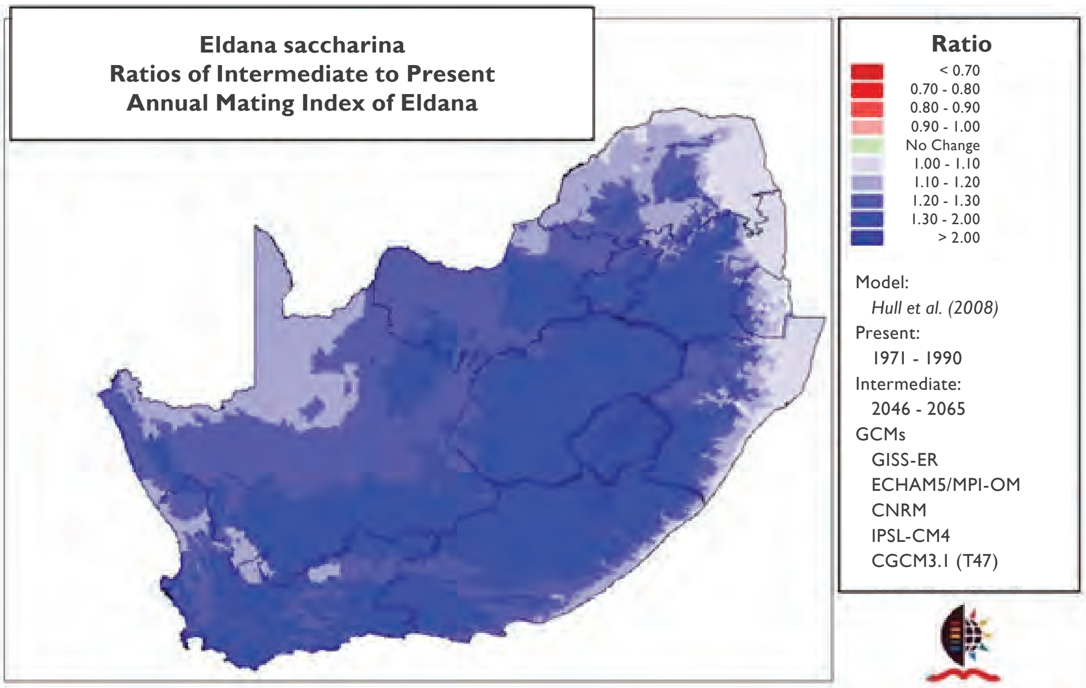

Figure 2.2: Ratio changes of mean annual mating hours of Eldana saccharina, from the present to mid-century, computed using outputs from multiple GCMs (Schulze & Davis 2014a).

data to develop predictions (for example, Blignaut et al. 2009).

Some modelling studies with greater levels of sophistication have explored relationships between yield, atmospheric CO_2 levels and nitrogen fertiliser (for example, Wallace 2013), but there have been no experimental or field trials to test model assumptions. Furthermore, while some work has identified potential future challenges in pest control (see Schulze & Davis 2014a **Figure 2.2**), few integrated studies have explored the potential economic impacts of changing incidence of pests and diseases. For some crops, early work is beginning to assess these risks (for example, Goebel & Sallam 2011 for sugarcane).

National level synthesis work indicates concerns with economic impacts and likely increases in irrigation demand (see also the water sector findings), because many irrigable regions of South Africa show about a 4–6% increase in average annual irrigation demand by mid-century. This is a major concern given that water is virtually fully allocated in most regions, and water supply itself may become more limiting, at least during more extended dry spells, even under wetting rainfall scenarios.

However, the offsetting effect of rising atmospheric CO_2 concentrations is seldom incorporated into such projections, some exceptions being projections on wheat yields by Wallace (2013), and on maize yields by Schulze and Durand (2016). This effect could be significant for agriculture and forestry production over the next few decades. This aspect urgently requires attention to improve risk assessments, preferably through the combined experimental and modelling approaches that have been used successfully to interpret CO_2 drivers of bush encroachment in the biodiversity sector.

These syntheses indicate significant potential positive and adverse impacts for the staple cereal crops, maize and wheat. In contrast, the potential zone for optimal sugarcane production does not show substantive losses in area of suitability, potentially showing some increases. High value export horticultural crops, including viticulture, are likely to be adversely affected, requiring innovation to avoid the worst effects. Impacts on important agricultural pests are inadequately explored, but initial work suggests that a number of pests and pathogens could increase their impacts primarily because breeding cycles are predominantly temperature driven (see Schulze 2011).

Climate change impacts on commercial forestry have been exhaustively assessed by Schulze and Davis (2014b), and indicate diverse trajectories for key species and genotypes for intensively managed plantation forests. In general, the optimum growing regions for most species and varietals shift significantly by mid-century, with several showing a potential expanded range by mid-century, but in many cases followed by potential range reductions if climate continues to change. Some hybrid varietals such as *Eucalyptus grandis x urophylla* may be more tolerant of substantive climate change (Schulze & Davis 2014b).

2.5.1.4 Human settlements

South Africa's Long Term Adaptation Scenarios (LTAS) process conducted the first national assessment of climate change impacts on urban and rural settlements, and also considered coastal settlements as a special case. A fundamental starting point for this sector is that human settlement vulnerability to climate change is determined both by exposure to environmental risk due to climate change, and by the adaptive capacity of at-risk households, communities and formal governance structures. Adaptive capacity in the sector is considered to be strongly related to socio-economic vulnerability, thus highlighting the high potential for investments that will have multiple benefits in addressing current socio-economic deprivation while at the same time increasing resilience to climate change risks.

In South Africa, the overlay of risk of exposure and adaptive capacity are place-specific, being related to local climatic, geographic and socio-economic factors, combined with local historical development footprints. In particular, Apartheid-era policies sharply divided settlements, placing historically disadvantaged households on urban peripheries remote from many economic opportunities, increasing both exposure to climate risk and reducing household economic security. A particular historical feature in South Africa is the recent increase in multiple risks due to the rapid rate of urbanisation on the periphery of many urban settlements, and the related demographic shift in rural settlements, in many respects further entrenching this historical legacy.

The LTAS report on human settlements identifies the following key climate risks and social vulnerabilities in this sector:

- ***Increased Temperatures:*** Heat stress impacts on human health exacerbated by urban heat islands, loss of productivity, reduced air and water quality, and increased energy demand for cooling.
- ***Extreme Weather Events:*** Rapid and slow-onset events include heat waves and droughts. High temperature events can lead to increased water demand, water quality problems, heat-related morbidity and reduced quality of life, food insecurity and increased risk of fire spread. Heavy rainfall and violent storms cause water quality problems, infections and water-borne disease, damage to infrastructure and economy, and loss of property. All of the above can increase loss of life particularly among the most vulnerable, namely the elderly, women and children.
- ***Sea Level Rise and Coastal Storm Surges:*** A particular risk for coastal settlements relates to direct exposure to storm surges exacerbated by sea level rise, which can lead to deaths and injuries, forced relocations, property losses, erosion and submersion of land, and damage to infrastructure and services. Longer term impacts would include

risks to groundwater due to salt water intrusion into freshwater reservoirs.

- ***Social Drivers of Vulnerability:*** These include the following five main types, but it is clear that poverty and related socio-economic factors underpin all of them:
  - *Access to Basic Services:* Households without access to electricity, water, sanitation and waste management services and other services such as disaster management and response are more directly impacted by rapid and slow-onset extreme climate events.
  - *Type of Dwelling:* Houses that are of inadequate construction quality, poorly located, or lack flood, fire and lightning protection, those without efficient water supply, not insulated or damp-proofed, are all a source of climate vulnerability. Informal housing is particularly vulnerable.
  - *Health:* Climate resilience is dependent on baseline health, including age. Children and the elderly are more susceptible to illness, heat stress, food insecurity and malnutrition, all of which are projected climate hazards.
  - *Economic Factors:* Poverty and unemployment link to many of the above-mentioned factors and reduce the ability of households to recover from climate shocks. Land tenure status is another important factor, with households having insecure tenure (such as squatters) being less likely or able to invest in adaptation.
  - *Demographic Factors:* Age-related vulnerabilities include multiple health related issues mentioned above, while asymmetrical domestic and tribal power relations may increase the vulnerability of women and children. Communities with a smaller than average proportion of working-age adults are particularly vulnerable (DEA 2015b, 6).

The risks, impacts and vulnerabilities for the three categories of human settlement addressed in the LTAS, namely urban, rural and coastal settlements, are complex and diverse, and both direct and indirect. They include:

- Direct impacts of weather on construction and other industries in terms of loss of production.
- Increases in the costs of water, liquid fuels and electricity as industrial inputs.
- Increased costs of labour linked to food, energy, water and transport costs.
- Disruptions to water and electricity supply reducing productivity.
- Interactions between climate change and air quality trends.
- Potential socio-economic impacts arising from regulation of carbon emissions (DEA 2015b).

Water is the basis of major vulnerabilities for urban settlements. A large proportion of urban dwellers, estimated at 4.5 million people at present, do not have direct access to water services. Where water treatment and delivery infrastructure and services are in place these are often rapidly deteriorating. Rising atmospheric temperatures will tend to both increase demand and adversely affect water quality. In a preliminary scoping of adaptation costs, Midgley et al. (2011b) calculated a range of increased costs to the economy of settlements amounting to ZAR 3.2 billion (2010 equivalent). The largest proportion of costs was due to recovery from storm damage to infrastructure (75%), while adding to water security made up 20% and additional water purification only 5% of additional costs due to climate change alone. Most importantly, these costs roughly doubled the required additional investment in water infrastructure due to development needs.

Extensive peri-urban development is occurring throughout South Africa, and this trend is of high relevance to climate impacts and adaptation. This is so because informal settlements and low cost or social housing estates are

Steve Tshwete municipality

likely to be particularly vulnerable to both extreme climate related events and to long term changes. Socio-economic vulnerability of peri-urban dwellers tends to be high (due to remoteness from workplaces and travel costs, lack of basic services, insecurity of tenure, and risk of asset losses). This is increased further if structures are vulnerable to extremes (both rainfall and temperature). Informal settlements may concentrate in areas that are not suitable for formal developments, often due to exposure to climate related events. Mixed rural / urban settlements that have features of both types pose specific challenges (and potential opportunities) due to lower densities.

Rural settlements have economies dependent to a greater or lesser extent on remittances, but with an additional strong dependency on local agricultural production and in a few cases on tourism. These livelihoods are all vulnerable to climate change. Vulnerabilities additional to those of peri-urban settlements include the following (DEA 2015b, 8):

- Diminished biodiversity and already degraded ecosystems are a source of rural vulnerability for poor rural communities that rely on informal resource use for survival as well as on jobs provided by biotourism.
- Physical isolation of rural communities are a result of poor rural roads which are vulnerable to flooding and erosion.
- Insecurity of tenure is often associated with the Communal Land Act or poor enforcement of farm workers' tenancy rights.
- Poor governance arrangements in rural areas, in which the responsibilities of traditional authorities and local authorities may not be clearly demarcated, or may not be exercised in a democratic and equitable manner with respect to allocation of land and land use rights.

Coastal settlement vulnerabilities are relatively poorly studied in South Africa, but have a focus on large metropolitan areas. The information available suggests that coastal settlements in general would be vulnerable mainly to effects of sea level rise, storm surges and coastal flooding, especially in conjunction with extreme river flows which may be exacerbated by upstream land use practices when settlements are located along rivers (which is often the case). Estuaries may also translate the effects of dry spells and droughts which could concentrate effluent discharges, damaging coastal ecosystems and their dependent economies. Impacts due to changes in marine and estuarine environments are less well understood, and may include losses of harvesting earnings due to ocean acidification, higher sea temperatures and changes to ocean currents. The following impacts specific to coastal settlements were identified by the LTAS (DEA, 2015b 9):

- Impacts on marine diversity are likely to affect livelihoods. It is estimated that climate change may reduce the value of South Africa's fisheries by up to 18%. This impact will be disproportionately felt by artisanal fishing communities.
- Rising sea levels and extreme weather events will result in partial or total inundation of some coastal areas, resulting in loss of property, damage to infrastructure and disruption of basic services.
- Rising seas could also "backwash" through the sewerage and wastewater systems, causing both damage and exposure to hazardous pollution.
- Increased groundwater salinity will threaten smallholders who depend on vulnerable aquifers.
- Marine recreational activities and tourism-supporting infrastructure such as access roads to beaches, and the aesthetic appeal of the coastline, are vulnerable in that they can reduce income from tourism.
- Coastal roads and railways are vulnerable to erosion and damage as a consequence of sea level rise and storm surges.
- Small fishing ports and harbours may need to upgrade their infrastructure – alternatively, rising sea levels may deepen some harbours, reducing the need for dredging activities.
- Critical infrastructure, such as the Koeberg nuclear power station, may be affected.


Catching dinner

A small number of urban metropolitan centres have conducted climate risk, impacts and vulnerability assessments, namely Gauteng, eThekwini Municipality and the City of Cape Town. This work is still at the stage of assessing individual sectors relevant to the individual centre, and integrated approaches that project likely impacts for South African cities as a whole have not yet been conducted. Sector specific research in the coastal cities of eThekwini and Cape Town has focused predominantly on sea level rise and the water related sector.

The water supply- and demand-related impacts for cities under climate change have been assessed in various studies. Such studies are strongly limited by the high uncertainty in rainfall projections. In the case of the Bredasdorp Municipality, a detailed study identified how significant increases in the cost of acquiring water under drought conditions might threaten the poorest sector of society if fiscal impacts threaten the viability of the municipality (Mukheibir, 2009).

2.5.1.5 Human health

The human health sector is one in which the South African development history and context plays a particularly important role in determining risk, vulnerability and impacts. As noted by DEA (2013b, 9), "South Africa faces complex and pressing public health challenges". These challenges interact strongly with factors that exacerbate climate risk in other sectors including adverse socio-economic conditions due to dense informal settlements, associated inadequate service delivery, water quality and food and energy security. Local research has begun to quantify impacts of climate on perceived climate-sensitive measures including diarrhoeal, respiratory, cardiovascular health and vector-borne infectious diseases (especially malaria). Long term climate change trends will tend to aggravate a number of such already existing health and environmental risks. The potential direct impacts will increase several key health risks, but in the short to medium term they centre on heat stress, which increases morbidity as measured by hospital admissions, and mortality, especially when combined with rainfall extremes. Unfortunately there remain significant knowledge and information gaps that do not permit more quantitative projections of human health impacts due to climate change in South Africa.

Ziervogel et al. (2014, 610) contend that "the health impacts of climate variability and change are increasing". These studies emphasise the role of socio-economic factors in exacerbating risk, especially relating to vulnerabilities to temperature stress and even mortality in informal settlements (Scovronick & Armstrong 2012). There are also direct implications of climate change for types of work associated with lower income, with observed decreased productivity of outdoor workers under high temperatures (Mathee et al. 2010, cited by Ziervogel et al. 2014). The LTAS highlights significant increases in the human discomfort index as warming trends continue (DEA 2013b).

The potential impacts on vector borne diseases remain a significant concern, even though malaria incidence in particular has declined due to intensive management efforts. Recent modelling predicts no overall increase in malaria prevalence for sub-Saharan Africa, but does show risks of shifts in the impact areas, with movements towards the west and south driven by climate change trends.

The interaction of climate change impacts together with other stresses on human health has recently been highlighted as particularly important in South Africa. The main interactive risks for the health sector are with:

- food security (worsened by hunger and malnutrition)
- non-communicable and communicable diseases (lower resistance)
- air quality
- occupational health
- natural disasters due to extreme events
- and even the suggestion of an interaction with mental well-being

The understanding of both trends and projections is limited due to the low availability of data, especially at local levels. Rectifying this would improve understanding of climate–human health relationships. Progress has been made on developing a conceptual model for the links between climate exposure and human health effects (Myers et al. 2011). However, much more work is needed on the linkages identified above, as none of these are yet included in integrated economic assessments.

2.5.2 Future risks due to extreme events

The inability of climate models to simulate future extremes with confidence, together with the limitations of impacts models in capturing the effects of extremes credibly, places a strong constraint on projections of future risks due to extreme events. At this point in time the projections are relatively few, with many lacking in detail, and relying more on extrapolation of past trends than on credible simulations. One of the few completed studies on extreme events, however, highlights the amplification of changes in extremes when projected changes in design rainfall for a specific duration and return period are compared with the corresponding changes to design streamflows (**Figure 2.3**). Nevertheless, the area of changes to extremes represents a major gap in estimating the future costs of climate change and the necessary effort in adaptation.

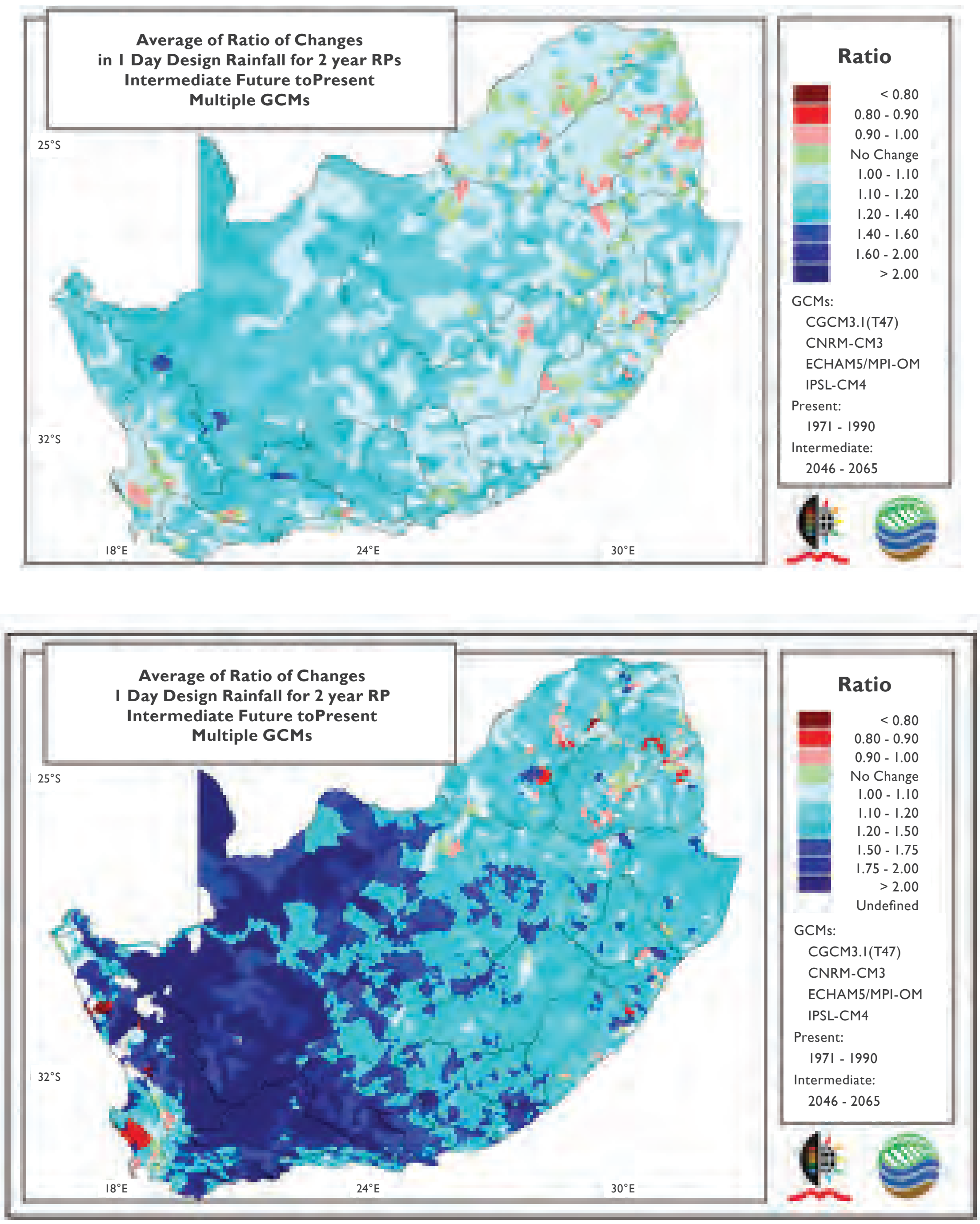

Figure 2.3: Comparison of averages of ratio changes from the present into the intermediate future between the 1 day design rainfall for the 2 year return period (top) and the corresponding changes to design streamflows (bottom), derived using outputs from multiple GCMs (Schulze 2012)

Extreme weather will also damage roads, railways, bridges, airports, tunnels and other transportation infrastructure, incurring delays and increasing maintenance costs. In addition groundwater changes may threaten to damage structures and foundations of the transportation system and higher temperatures will cause stress to construction materials, in particular steel. Extreme weather will also result in increased traffic congestion and collisions.

Extreme weather events and climate change furthermore pose a threat to human health through increased temperature-related morbidity and mortality, reduced water supply and quality, increased exposure to waterborne diseases and disease vectors such as the malaria mosquito, and problems with water supply.

2.5.3 Cross-sectoral, cumulative and interactive risks

When considered separately, each sector referred to above shows some level of vulnerability to climate change. Understanding of these sector-specific risks and socio-economic impacts is improving, but what is missing is analysis of how impacts might be amplified (or perhaps reduced) by links between sectors, by an increasing frequency of adverse climate conditions (cumulative effects) and by the overlay of multiple adverse climatic effects (for example high heat stress in combination with cumulative drought). The approaches mentioned in **Section 2.2.3** have begun to address this shortcoming, but much remains to be done in developing both credible impact scenarios and the modelling approaches needed to assess their socio-economic impacts. This effort could be based on deliberate monitoring for such interactions in different regions of South Africa, and from analysis of data and information that is already recorded, but has not been brought together. For example, SAWS is approached by stakeholders for confirmation or otherwise of extreme weather events for the purposes of insurance claims. This indicates that there is a commercial appetite for good quality information which, if well monitored and recorded could provide useful guidance to trends in impacts and the effectiveness of adaptation responses

What will be important is an understanding of relative resilience of different sectors to adverse impacts, and then to design responses that allow more resilient sectors to support those that are less resilient. One of the first of such opportunities identified is ecosystem based approaches to adaptation, where resilient ecosystems may support adaptation in sectors such as water, agriculture and even human health.

Finally, Noble et al. (2014, 837) highlighted a potential risk where implementing adaptation "in one location or sector could increase the vulnerability of another location or sector, or increase the vulnerability of the target group to future climate change". In other words, adaptation action in one sector or location has the potential to decrease resilience if inappropriately designed or implemented. They noted that maladaptation can arise if not enough is known about "the full range of interactions arising from the planned action". Very little is known about these kinds of risks, because there are too few efforts "assessing the processes of implementation and evaluation of actual adaptation actions".

2.6 Challenges, Gaps and Opportunities

Five main types of challenges, gaps and opportunities are discussed in this section of the report, namely:

- sectoral, namely sectors that have not yet received proper consideration, including industry, mining and the financial sector (insurance, value chains)
- observation and information (namely the platform for decision making)
- analysis and integration (namely the tools to support decision making)
- implementation (namely the mechanisms for achieving outcomes)
- monitoring and evaluation (namely the feedback loop to assess effectiveness and guide adjustments in approach)

More detail on these five types is provided below.

- ***Sectoral:*** Climate impacts and adaption work in South Africa have followed an international trend in focussing on sectors directly affected by climate change and variability, namely agriculture, water, biodiversity and ecosystems, due to their being the focus of Article 2 of the UNFCCC, and to the availability of impact modelling capacity and technology. More recently, sectoral efforts have expanded into consideration of marine ecosystems, human health and human settlements. Industrial, business and financial sectors have, to date, been particularly poorly represented, especially because of the integrated nature of their likely responses to climate changes, and the lack of appropriate simulation tools to assess impacts.
- ***Observation and Information:*** The basis has been laid for a potentially effective national system linked to sub-national nodes, with substantial historical reach in several sectors to allow analysis of trends and to fast track learning about risks, impacts and vulnerabilities. What is critical at this point is to conceptualise and design a system that is able to gather, store and retrieve data and information from a wide range of sectors, at a range of spatial and temporal resolutions, and with a range of uncertainty attached to the observations. The critical decisions include the initial data and information sets to be part of such a system, the platform and design of the system, its hosting arrangement, and protocols relating to quality control of submitted information. A national system such as this would be vital in supporting national implementation of adaptation responses, and monitoring and evaluation of outcomes.
- ***Analysis and Integration:*** There is a distinct lack of integrated assessment capacity for climate change impacts and adaptation in South Africa. Such assessments are important in integrating diverse types of information on climate change impacts, and translating these into a more holistic understanding of vulnerabilities in order to identify priorities for adaptation. A key issue is how to incentivise practitioners to conduct the necessary analytical and synthetic work. Links with universities provide an obvious first step for unlocking substantial analytical skills, with strong win-win benefits both for the national interest and for the individual student's and mentor's productivity. An excellent example is the availability of health-related trend data gathered by medical facilities country-wide which could provide numerous post-graduate study opportunities and thus train new entrants into the field of applied climate change science. Ziervogel et al. (2014) highlight analysis and integration limitations due to "a lack of climate scenario products; under-synthesised and potentially contradictory climate information; incomplete impacts modelling approaches and inadequate process understanding; poor traceability between impacts assessments and the climate scenarios on which they are based; [and] inadequate socio-economic and vulnerability assessments" (Ziervogel et al. 2014, 612). Many opportunities exist to address these shortcomings.
- ***Implementation:*** South Africa's National Climate Change Response White Paper identifies and prioritises "climate-resilient development", a directive that has not been fully taken up in South Africa's National Development Plan. Both the LTAS (DEA 2015a) and Ziervogel et al. (2014) highlight that adaptation must be linked closely to South Africa's national development objectives, and "should focus on multiple synergies – prioritising activities that fulfil a range of objectives, of which climate adaptation is one" (Ziervogel, 2014 615). Early implementation of adaptation responses is rare, but as some sectors and projects develop strategies for implementation and access funding to do so, it is likely to become more common. An example is the work of South Africa's National Implementing Entity, SANBI, which is in the process of implementing a set of interventions to increase resilience to climate change in a number of rural settings. It will be essential to use opportunities

such as this to gain as much learning as possible about effective implementation. Ziervogel et al. (2014) have suggested that implementation could be enhanced through the "establishment of a dedicated national facility for impacts and adaptation support that can also function as an intermediary for connecting scientists, policymakers and stakeholder groups" (Ziervogel, 2014 614).

- ***Monitoring and Evaluation:*** The monitoring and evaluation of adaptation responses in South Africa is virtually a clean slate, providing the opportunity for the implementation of a purpose-designed monitoring and evaluation (M&E) system. Currently, few adaptation activities are well documented by the complementary communities of policy makers, practitioners and researchers. This indicates the likely value of more transdisciplinary, action-research oriented approaches, and an opportunity for these communities to co-operate in documenting and analysing adaptation activities in novel partnerships. These could include relationships between, for example, municipalities and academic institutions in designing and using systems for monitoring and evaluating the effectiveness of adaptation responses and their fiscal effectiveness.

2.7 Policy Implications

Relevant policy implications from the above relate to adaptation and mitigation responses, and the role of an enabling environment for enough capacity, technology, skills and finance to achieve global, national, sub-national and local goals. South Africa's apparent sectoral vulnerability to levels of global warming higher than 2 °C supports a global goal below this level. Additional vulnerability could result from cross-sectoral impacts that are not yet well understood, while the socio-economic vulnerabilities that could result from interdependencies between sectors of the economy are also a policy concern. All this indicates that, in terms of mitigation, a more ambitious global goal would be preferable both to avoid the most serious adverse outcomes, and to allow adaptation responses to have the highest chance of success. The latest global synthesis shows that a slower rate of climate change, coupled with a lower amount of change, is preferable, because it lowers the probability of exceeding adaptation limits (IPCC 2014).

Because of the remaining gaps in knowledge and understanding of complex interactions between impact outcomes and the resulting risks and socio-economic effects, a targeted monitoring and evaluation system will be critical to inform policy makers of rates of change in impacts and vulnerability, and the effectiveness of adaptation responses. Monitoring and evaluation actions need to be able to detect changes in a variety of important impact areas and inform the appropriate responses. The key areas are identified, as follows:

- ***Risks, Impacts and Vulnerabilities (RIV) Resulting from Long Term Climate Change:*** These require the ongoing collection of climate data, its quality control, synthesis and analysis for trend detection. The following elements are relevant:
    - Long term trends already reported in this report provide a basis for immediately identifying observed trends and the regions where these are strongest, and where a greater monitoring effort is required.
    - Conversion of raw data into climate indices (specifically WMO climate indices applicable for South Africa), should be effected.
    - Desired adaptation outcomes informed by sectoral requirements in Chapter 5, Desired adaptation outcomes, of the National Climate Change Response White Paper (DEA, 2011a) should be identified.
- ***RIVs Resulting from Extreme Weather Events:*** The following elements are relevant:
    - Establishing national maps of historical variance in key climate indicators to allow extreme events to be identified with confidence.

Woman hoeing field

- Linking National Disaster Management Centre climate-relevant incident reports to established historical variance.
- Overlaying the two elements above to identify regions that are more and less resilient to extreme weather events.

• ***Drivers of Vulnerability:*** These would include:
  - Socio-economic conditions that would increase vulnerability.
  - Geographic and topographic features that would tend to increase exposure to adverse impacts.
  - Ecological or environmental features that would tend to modify exposure and vulnerability (such as healthy ecosystems that provide climate adaptation services).

• ***Impacts Scenarios:*** As skill and knowledge increase, better information will become available for assessing vulnerability to both long term climate change and extreme events. The most relevant elements are:
  - improved scenarios of cross-sectoral and interactive risks
  - identifying where these are most relevant

• ***Adaptation Responses:*** It is important that appropriate responses be recorded, and their implementation and effectiveness be tracked with respect to the investments made. This will allow ongoing guidance that is relevant for allocating adaptation resources. The most immediate effort relevant to, for example, major droughts such as that from 2014 to 2016, is the location and type of responses being implemented including:
  - adjustments of policies and practices such as regulations and water restrictions
  - investments in infrastructure
  - implementation of inter-basin transfers
  - ecosystem-based adaptation via wetland rehabilitation
  - other efforts in combating water wastage

Policy direction on climate change adaptation could be well informed by considering those who are most adversely affected by climate change impacts. Two relevant sets of indicators that are providing important information about this sector of society are the Millennium Development Goals and the indicators identified by StatsSA (2014) in the recent report on poverty dimensions.

Five of the eight Millennium Development Goals (MDG) can be linked directly to climate change impacts. These are:

- MDG 1 on eradicating extreme poverty and hunger
- MDG 4 on reducing child mortality
- MDG 5 on improving maternal health
- MDG 6 on combating HIV / Aids, malaria and other diseases
- MDG 7 on ensuring environmental sustainability.

The StatsSA report on poverty dimensions identifies some key aspects that overlap with, or enhance, the climate-sensitive MDGs. These are nutrition, child mortality, and aspects of housing quality and household assets.

It would be important for policy purposes to be able to isolate the role of climate impacts in driving these trends, because they would require specific interventions that could prevent reversals of recent gains in poverty alleviation.

2.8 Key Messages

South Africa's economy and its people face appreciable risks due to the potential impacts from ongoing climate change. These risks are likely to increase significantly if global warming exceeds the ambition stated in the UNFCCC's Paris Agreement of remaining below a limit of 1.5 to 2 °C above pre-industrial levels. This is because South Africa's climate is projected to warm between 1.5 and 2 times as fast as the global average, potentially resulting in drastic socio-economic and environmental effects.

Sectoral risks due to "slow onset" climate change are reasonably well understood owing to the well-developed human and technological capacity to make projections of risk by in-country practitioners. Increasingly adverse impacts with ongoing warming are indicated for water security, agricultural production and food security, human settlements, human health and well-being, as well as for certain natural ecosystems on land and in the ocean.

Risks due to the impacts of extreme climatic events are being better recorded and monitored, but future projections of such risks remain less well developed and there are thus high levels of uncertainty.

The combined effects of these adverse sectoral effects on human livelihoods and the economy are also less well understood than effects on individual sectors, but the capacity to make integrated assessments in-country is increasing. The integrated assessments show that the economy provides some capacity to adapt via pricing signals to encourage more efficient investment of financial and human resources, for example in increased agricultural production.

Potential limits to adaptation resulting from resource constraints, for example in water supply, require urgent attention through the application of integrated assessment approaches.

As a middle income country with a legacy of inequality that increases the vulnerability of the poor, adaptation to climate change represents an opportunity for South Africa to craft a more sustainable socio-economic development path.

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